

**RADAR RESPONSE OF VEGETATION:
AN OVERVIEW**



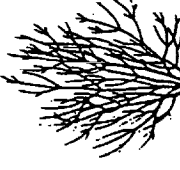

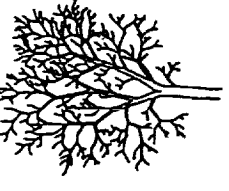
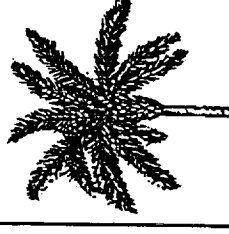
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**Fawwaz T. Ulaby and M. Craig Dobson
The University of Michigan**

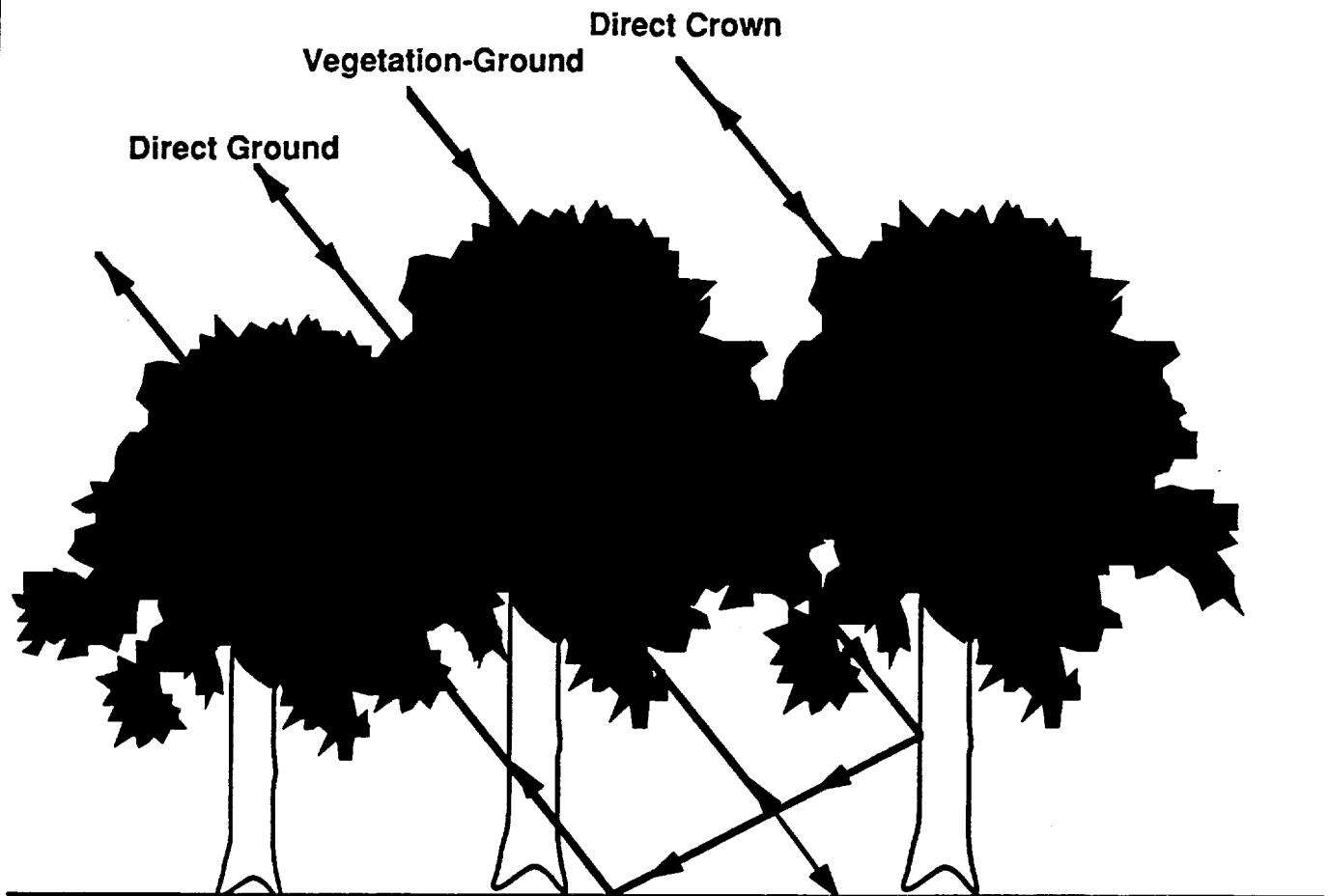
- **Vegetation Classes**
- **Soil Scattering: (1) Backscatter
(2) Forward Scattering**
- **Radar Response**
 - **Vegetation Biomass**
 - **Vegetation Structure**
 - **Temporal Variations: (1) Short Term (hours to days)
(2) Long Term (Seasonal)**
 - **Effect of Rain**
- **Emergence of a User Community**
- **Concluding Remarks**

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STRUCTURAL CLASSIFICATION OF VEGETATION FROM SAR

Growth Form	Herbaceous		Woody			
	Blade-like	Broadleaf	Shrubs	Excurrent	Decurrent	Columnar
Structural Characteristics	 (i.e., grass, corn)	 (i.e., soybeans)	 (i.e., alder)	 (i.e., pine and spruce) Gymnosperms	 (i.e., oak and maple) Angiosperms	 (i.e., palm) Angiosperms
	none	none	Many small trunks with characteristic orientation distributions	conical layered dielectric	cylindrical, forked layered dielectric	Monocotyledons cylindrical homogeneous dielectric
Branches	some non-woody stalks or stems	some non-woody stems	many small branches & stems	branch size and orientation varies with height • large branches-planophile • many small stems-erectophile branches tend to be long and thin	many forked with few horizontal elements branches tend to be short and thick	none
Foliage	blade-like erectophile	broad leaves	blade-like or broadleaves	very high like-polarized σ^0 moderate	broadleaves	blade-like in clump at top of trunk
General Scattering Properties	low to moderate σ^0 dominated by surface scattering $\sigma_{VV}^0 \geq \sigma_{HH}^0 \gg \sigma_{HV}^0$ zero mean $\Delta\phi$	moderate σ^0 dominated by $\sigma^0(f, P, \theta)$ dependent upon trunks & branches uniform $\Delta\phi$	moderate σ^0 dependent upon trunks & branches uniform $\Delta\phi$	σ_{HV}^0 dominated by ground-trunk and few large branches $\sigma_{HH}^0 \geq \sigma_{VV}^0$ $\sigma_{HH}^0 / \sigma_{VV}^0 = f$ (trunk biomass) broad distributions of $\Delta\phi$	high σ^0 dominated by large branches, $\sigma_{HH}^0 \geq \sigma_{VV}^0$ $\sigma_{HV}^0 = f$ (branch biomass) broad distributions of $\Delta\phi$	moderate σ^0 large crown structures may dominate σ^0 low transmissivity through crown non-zero mean $\Delta\phi$
$f < 5 \text{ GHz}$						
$f > 5 \text{ GHz}$	moderate to high σ^0 dominated by vegetation $\sigma_{VV}^0 \approx \sigma_{HH}^0 > \sigma_{HV}^0$	mod. to high σ^0 stem orientation and leaf size very important	high σ^0 dominated by branches and stems	mod. to very high σ^0 , can vary seasonally with foliage and stem properties	high σ^0 determined by crown	

RADAR SCATTERING MECHANISMS



- Direct Ground Backscatter
- Vegetation-Ground Bistatic Scattering
 - Trunks
 - Leaves (needles)
 - Branches
- Direct Crown Backscatter

SOIL BACKSCATTERING

A. Theoretical Models

- Small Perturbation Model
- Physical Optics Model
- Geometric Optics Model
- Phase Perturbation Method
- Full Wave Model
- Integral Equation Model

Models agree with experimental observations only under certain conditions. Overall, models not useful.

B. Michigan Empirical Model

- Frequency Range : 1-10 GHz
- Angular Range : 20° - 70°
- Roughness range : $s = 0.32$ cm to $s = 4.0$ cm
(expected validity for any $s > 0.3$ cm)
- Moisture range : 0.05 g/cm³ to 0.31 g/cm³

Moisture Sampling Depth

L-Band (1.25 GHz) : Average Moisture of Top 10 cm layer

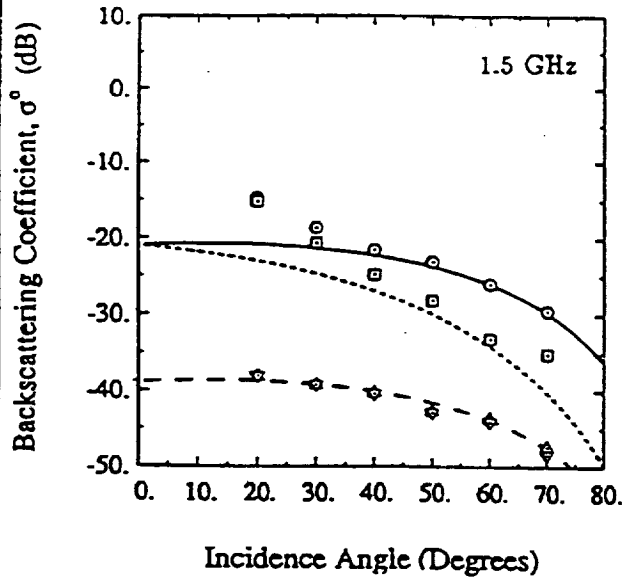
C-Band (5.3 GHz) : Average Moisture of Top 3 cm layer

X-Band (9.5 GHz) : Average Moisture of Top 1 cm layer

$$\text{Sampling Depth} \approx \lambda / 3$$

• Model Verification For A smooth Surface ($s=0.4$ cm)

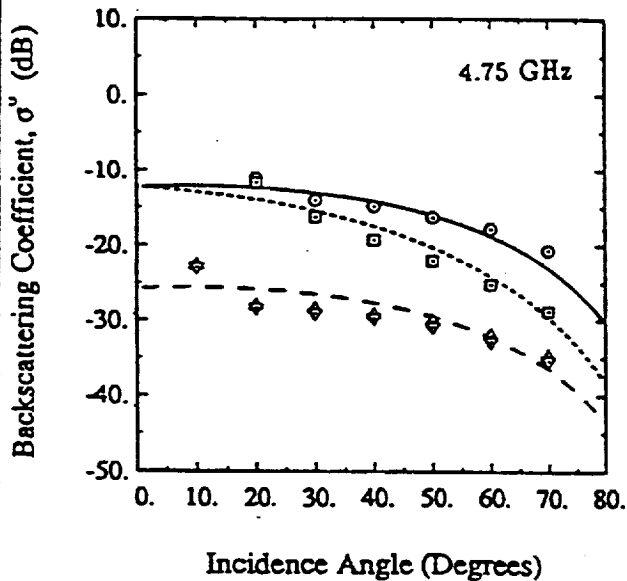
1.5 GHz



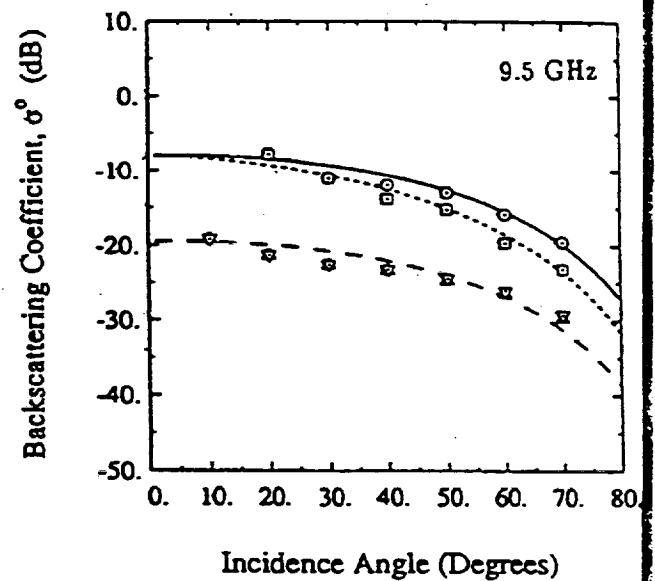
$s = 0.4$ cm
 $m_v = 0.29$

— σ°_{ww} , Model
- - σ°_{hh} , Model
- · - σ°_{vh} , Model
○ σ°_{ww} , Measured
□ σ°_{hh} , Measured
▲ σ°_{vh} , Measured
▼ σ°_{hh} , Measured

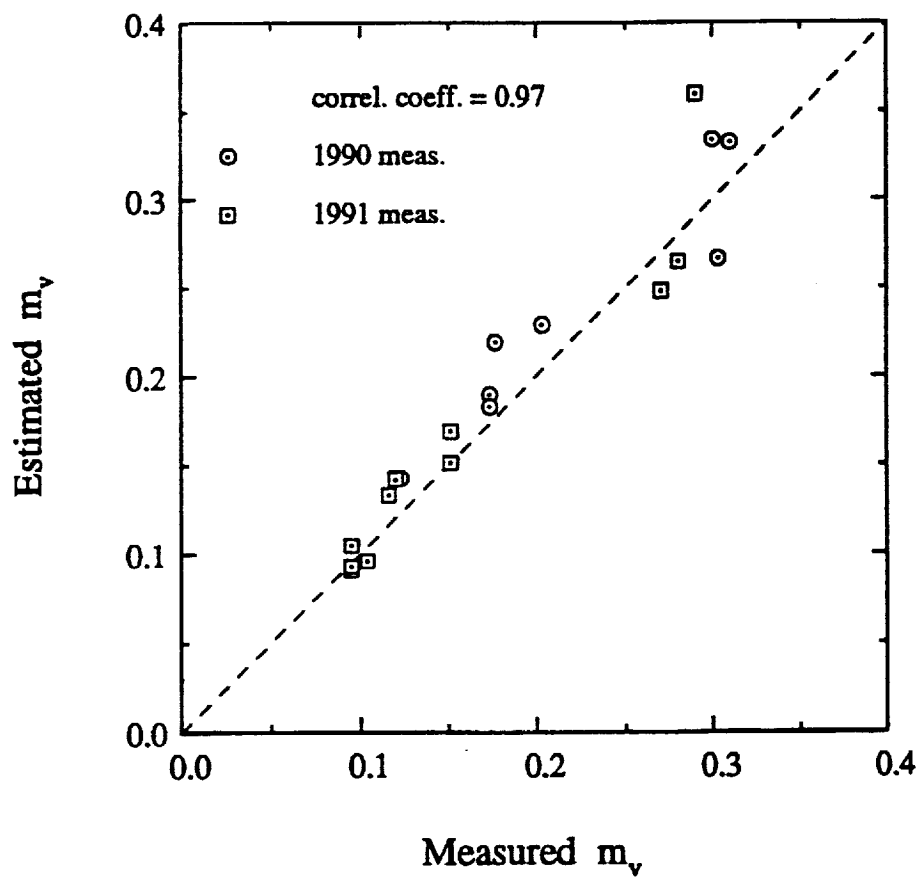
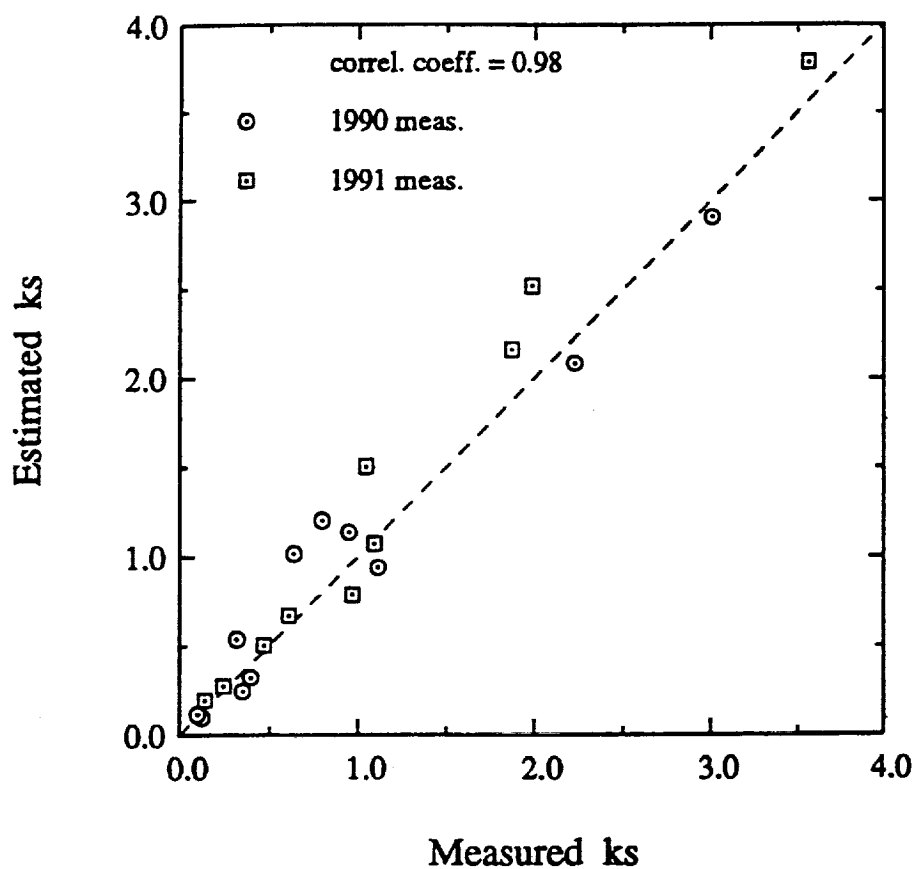
4.75 GHz



9.5 GHz



MOD-3

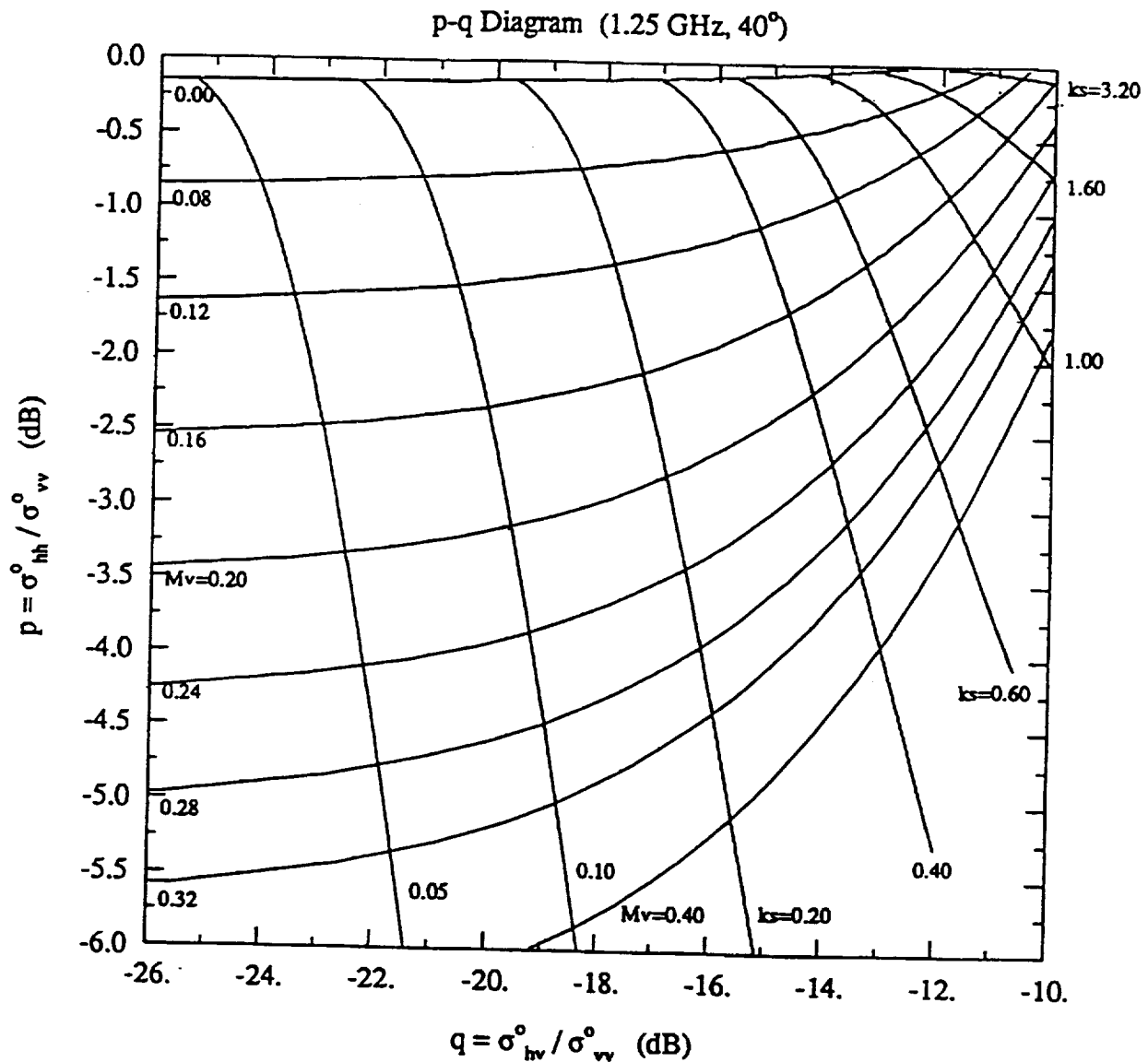


Inversion Algorithm

If radar measures σ_{vv}^0 , σ_{hh}^0 , and σ_{hv}^0 at a given frequency and angle, both s and m_v can be determined from the ratios:

$$p = \sigma_{hh}^0 / \sigma_{vv}^0$$

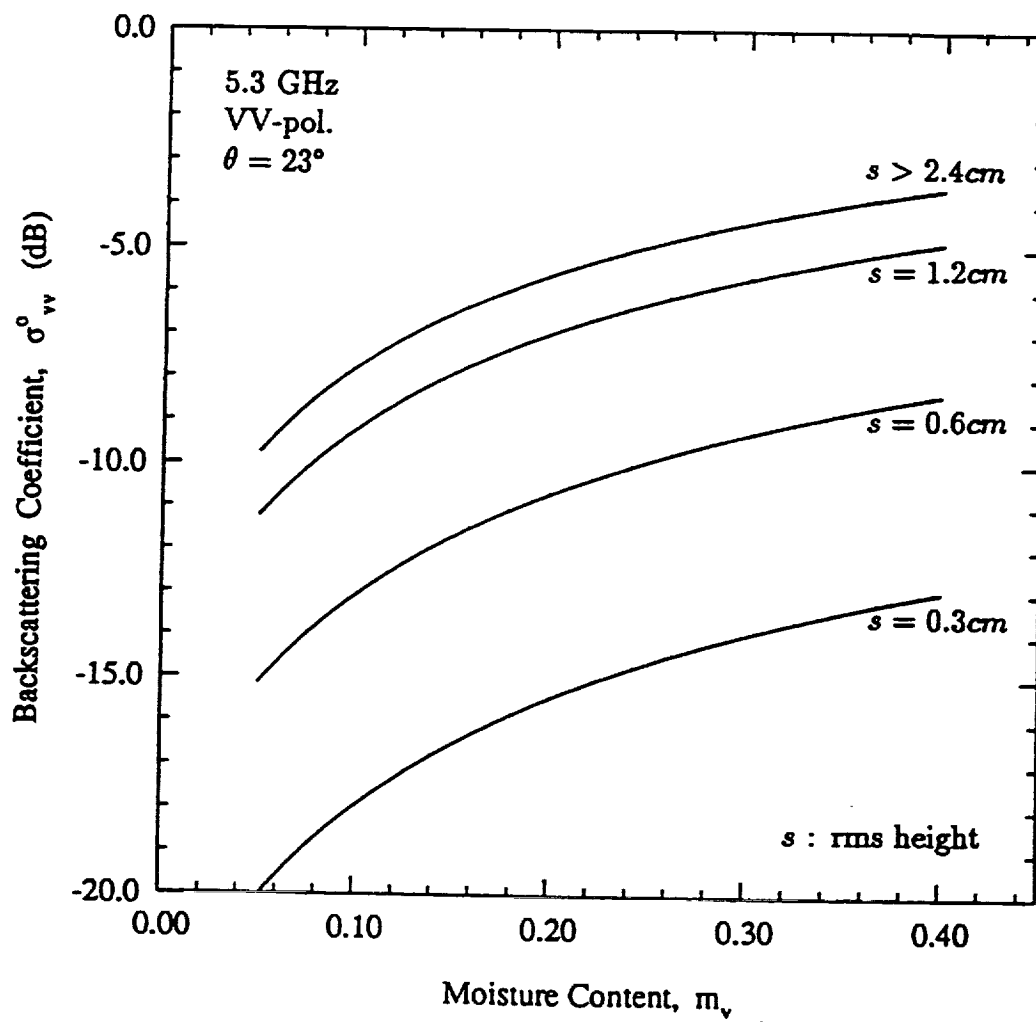
$$q = \sigma_{hv}^0 / \sigma_{vv}^0$$



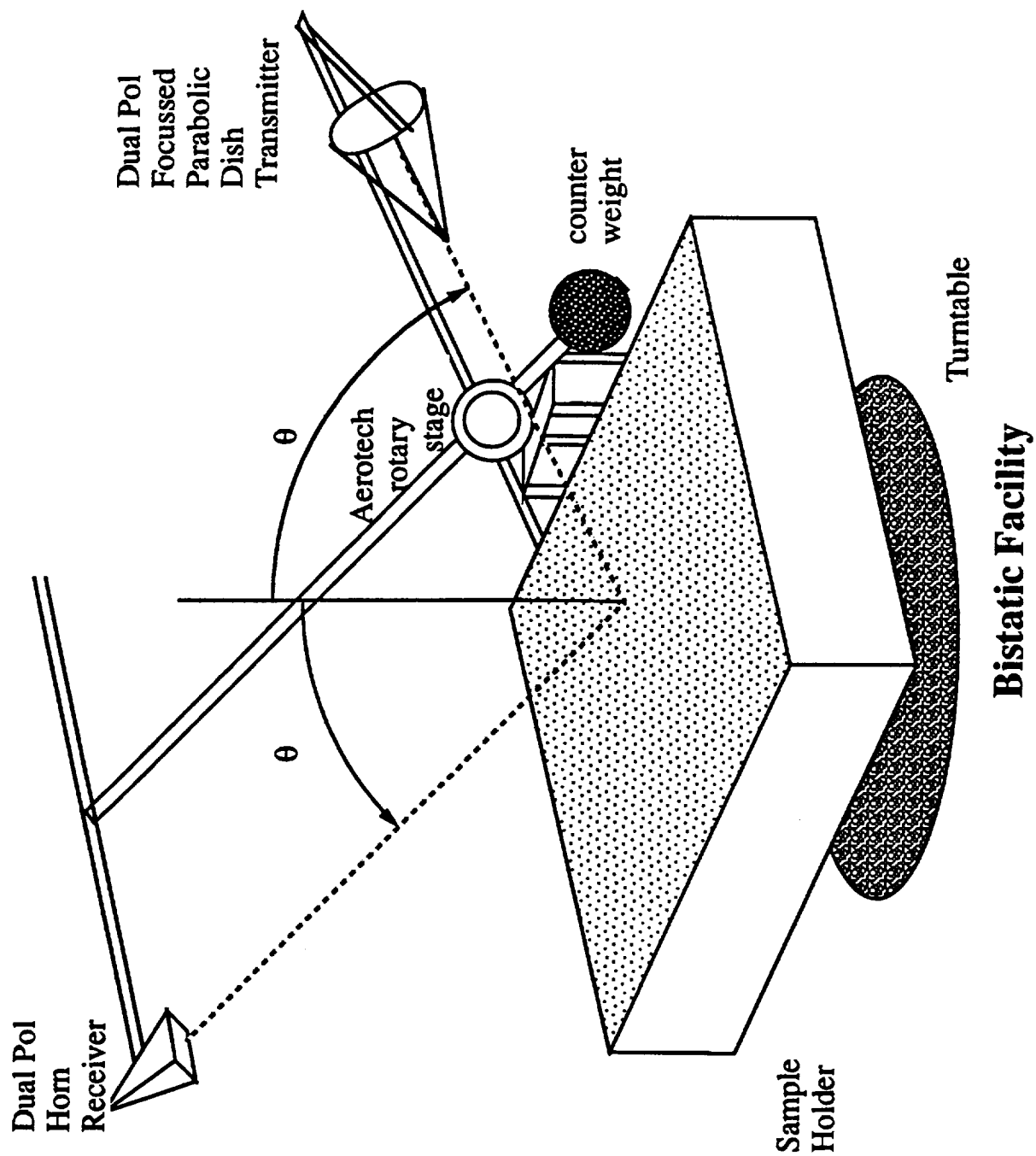
Note: $p(\text{dB}) = 10 \log(\sigma_{hh}^0 / \sigma_{vv}^0) = \sigma_{hh}^0(\text{dB}) - \sigma_{vv}^0(\text{dB})$
 $q(\text{dB}) = \sigma_{hv}^0(\text{dB}) - \sigma_{vv}^0(\text{dB}).$

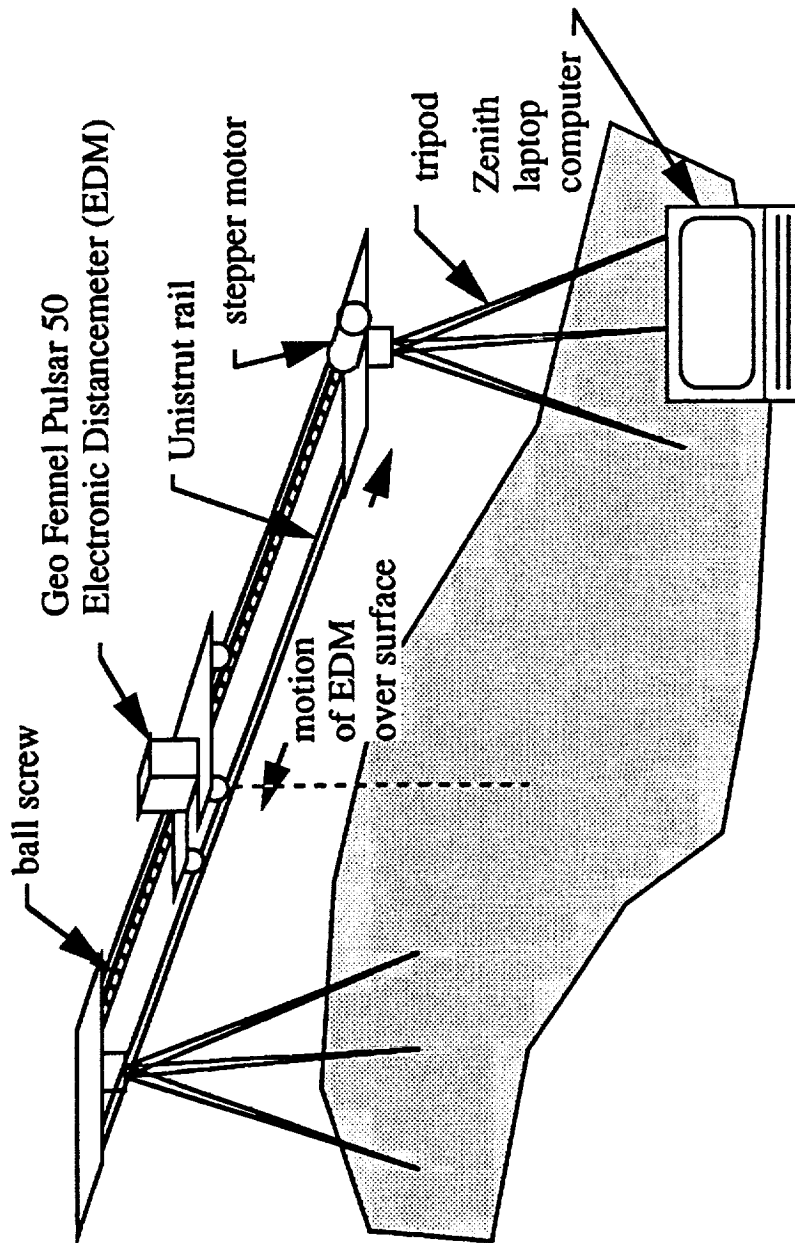
ERS-1 SAR Response $\theta = 23^\circ$

vv Polarization

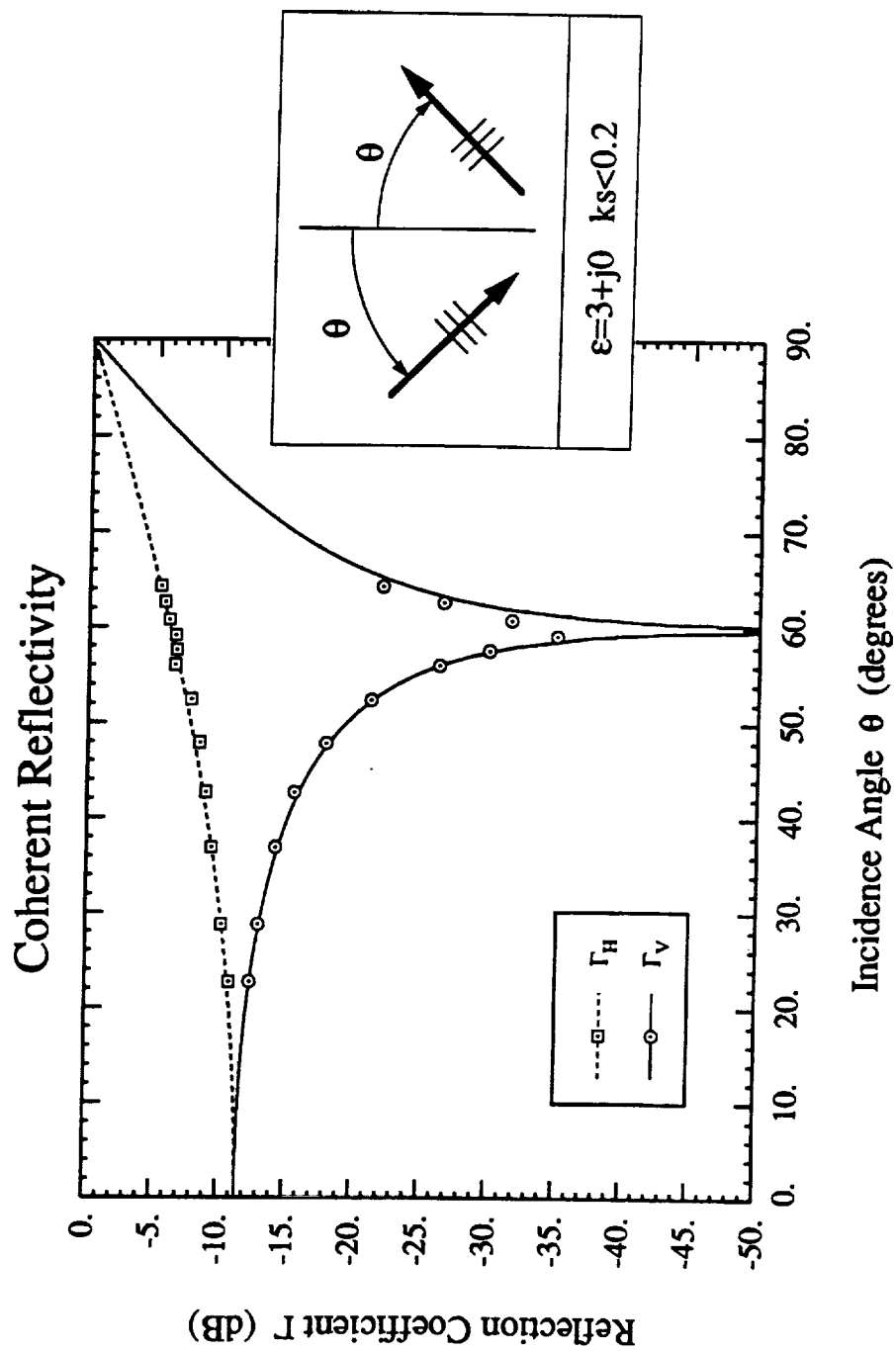


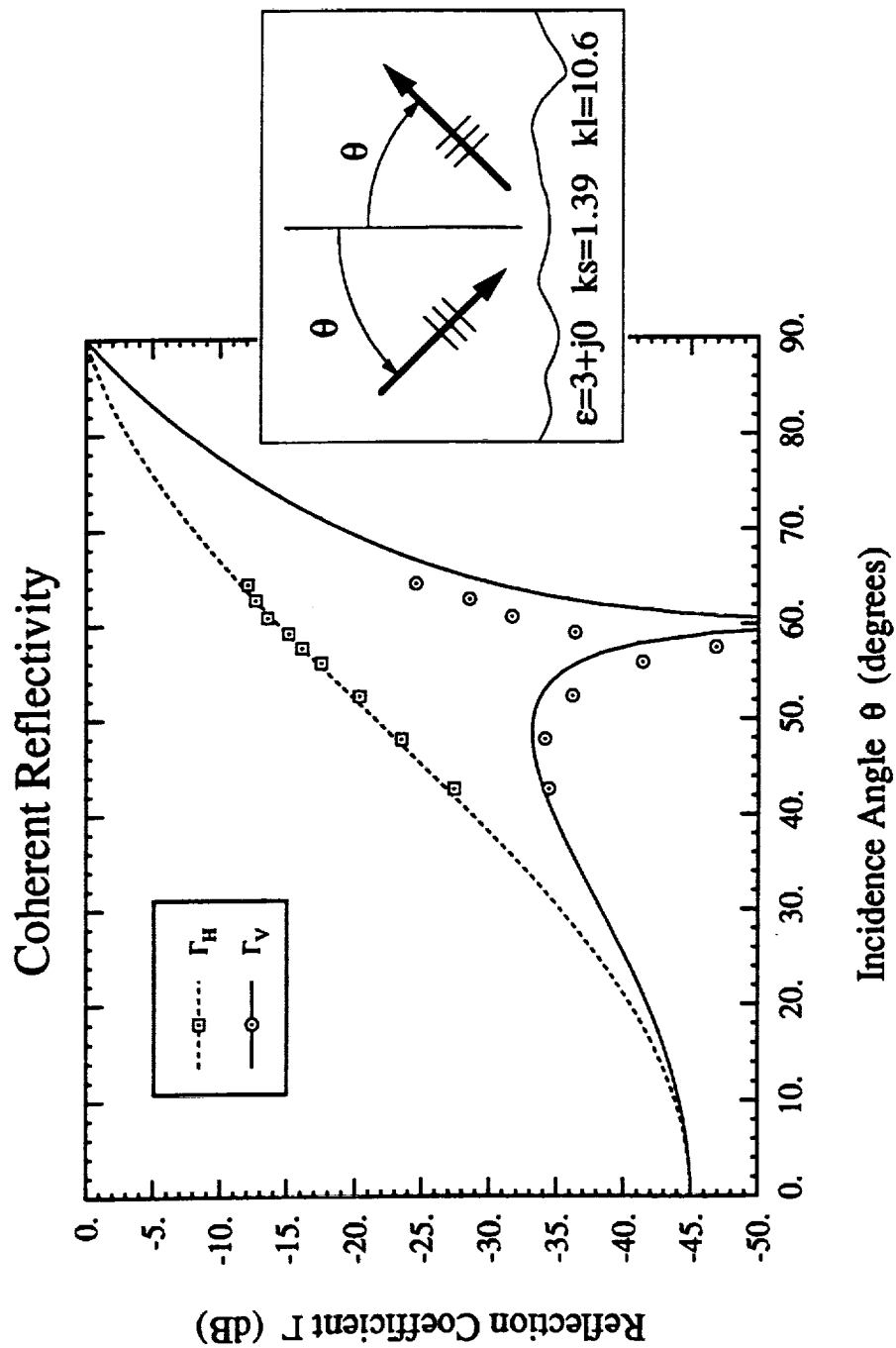
RADIATION LABORATORY



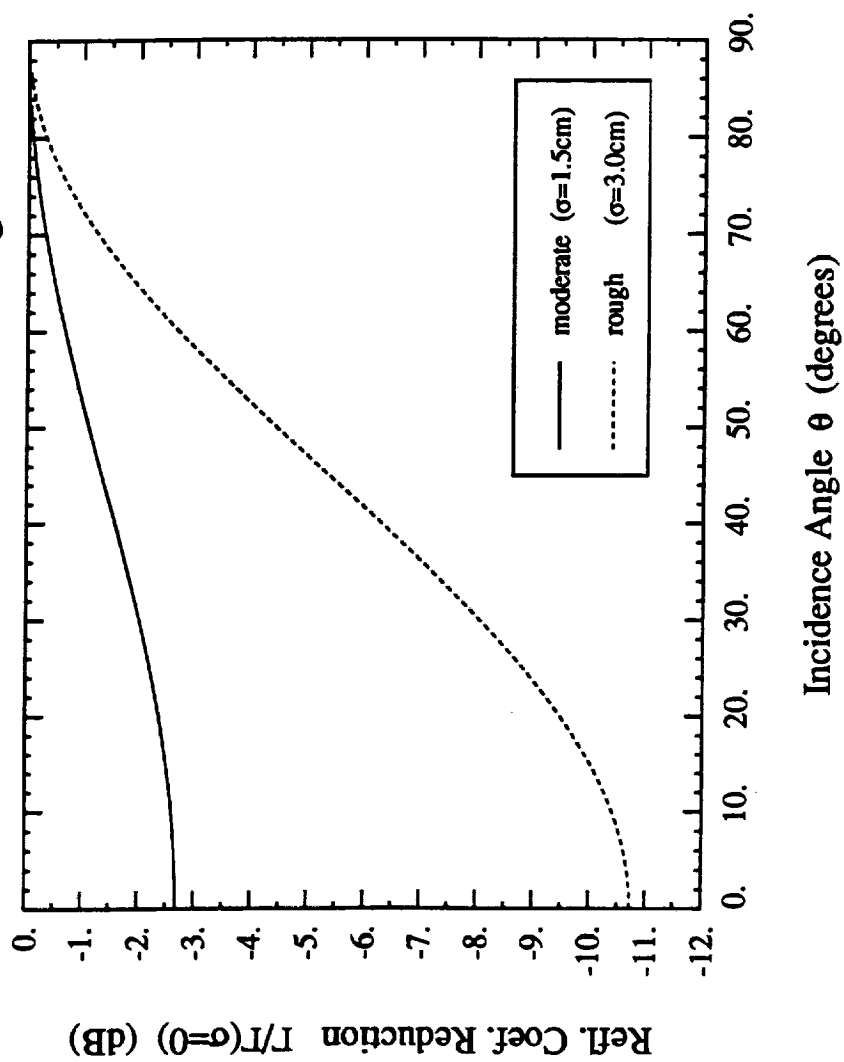


Laser Profiler





Reduction of Reflectivity by Surface Roughness at L-band



RADAR RESPONSE TO VEGETATION

- **OBJECTIVES**

- To Discriminate/Classify Vegetation Classes
- To Estimate Biomass
- To Estimate LAI
- To Estimate Soil Moisture
- To Monitor Changes (deforestation, growth, stress, etc.)
- Other

- **VEGETATION CANOPY**

- Structure: (1) Macro (tree or plant scale): Tree height, density, ground cover
(2) Micro (wavelength scale): Leaves, branches
- Dielectric Properties
- Ground Cover (soil, debris, undergrowth, etc.)

- **TOOLS**

- Wavelength
- Polarizations
- Phase Statistics
- Incidence Angle
- Time

- **APPROACH**

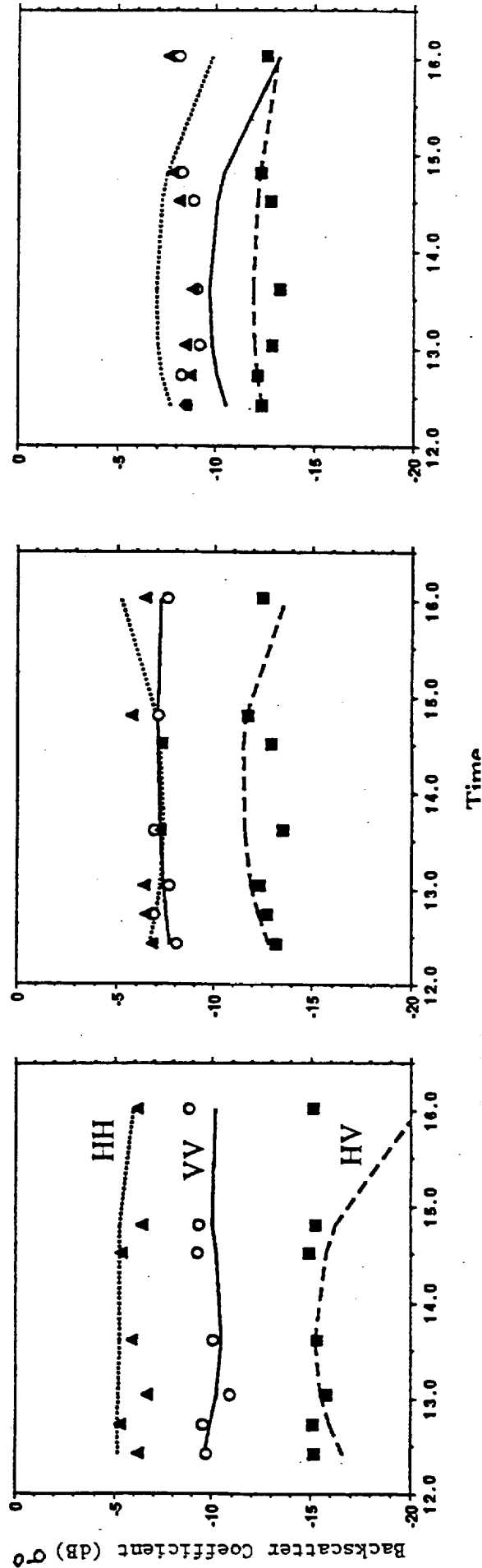
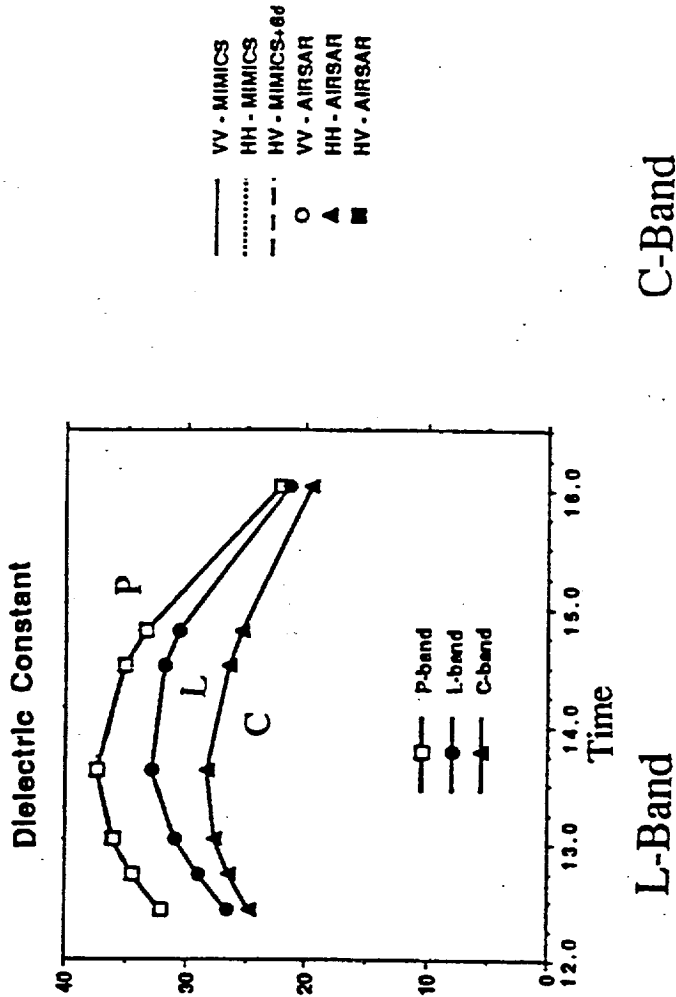
- Theory
- Observations
 - Lab
 - Field
 - Air SAR
 - Satellite

DIURNAL VARIATION IN σ^0

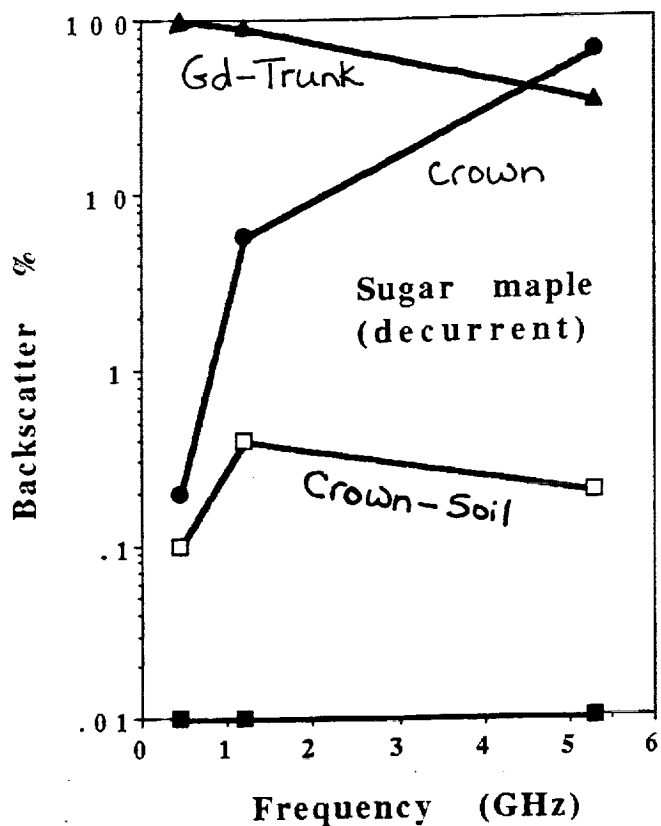
Humid Temperate Forest Loblolly Pines at Duke Forest

While ϵ^* of trunks are found to vary by 30%,
 σ^0 varies by only $\approx 1\text{dB}$

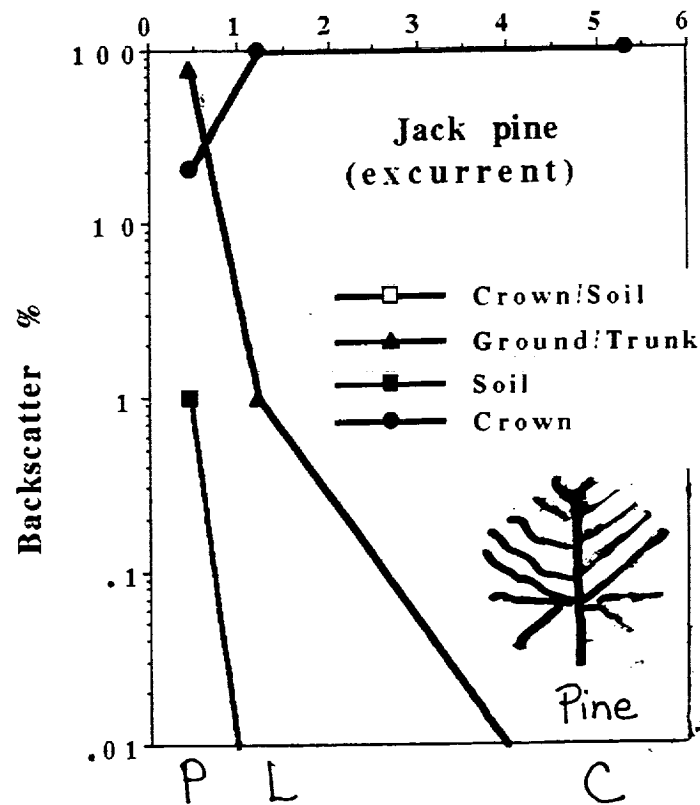
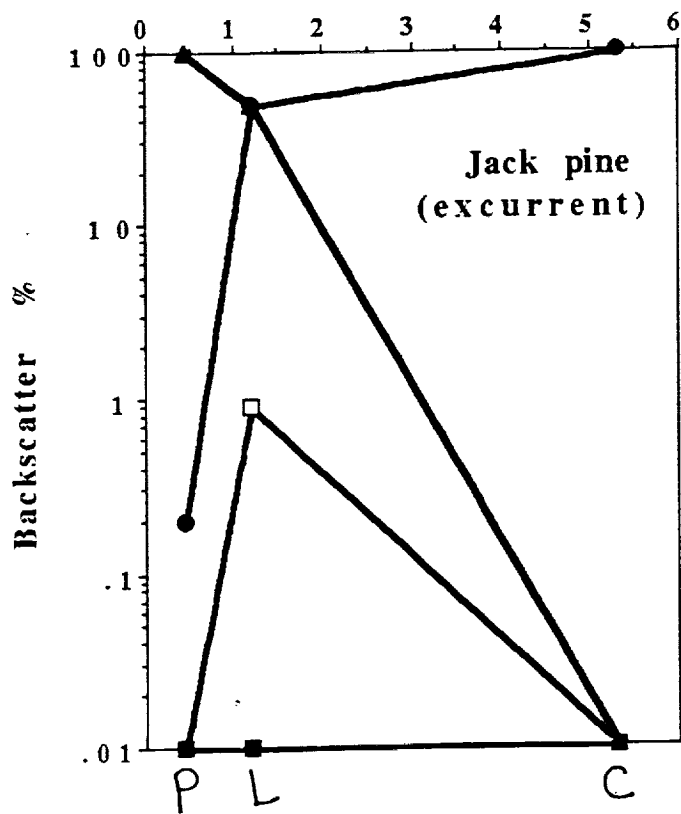
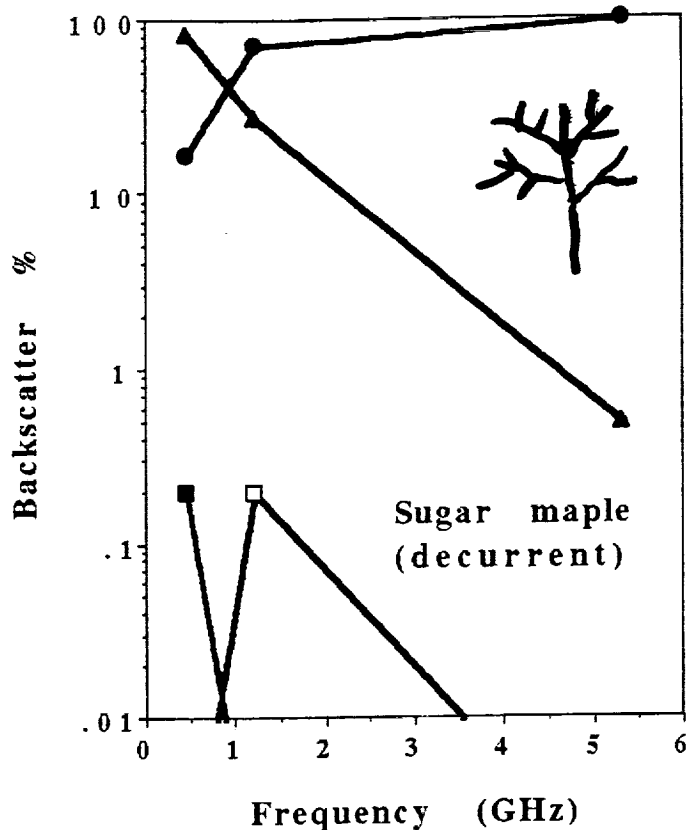
Calibration accuracy is 1dB

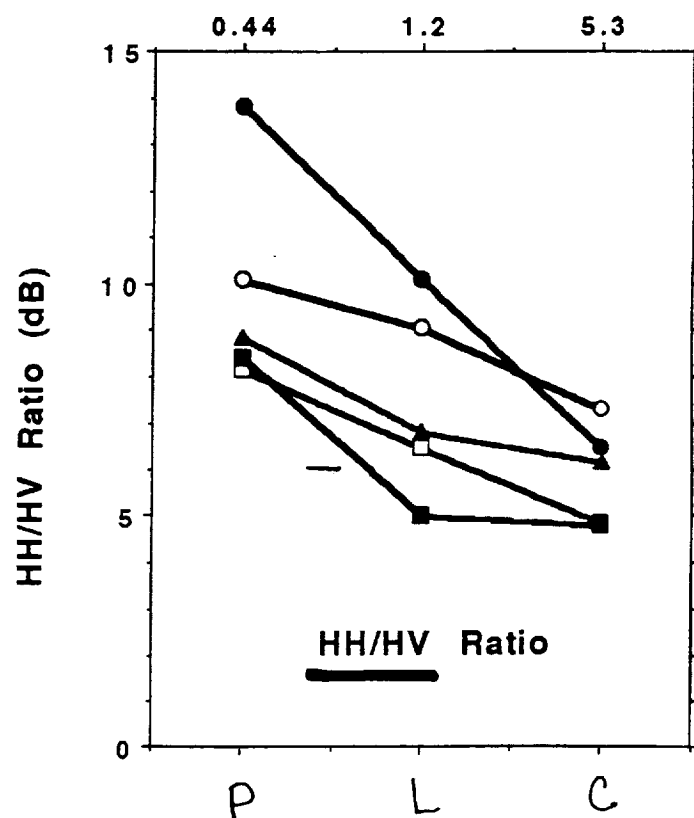
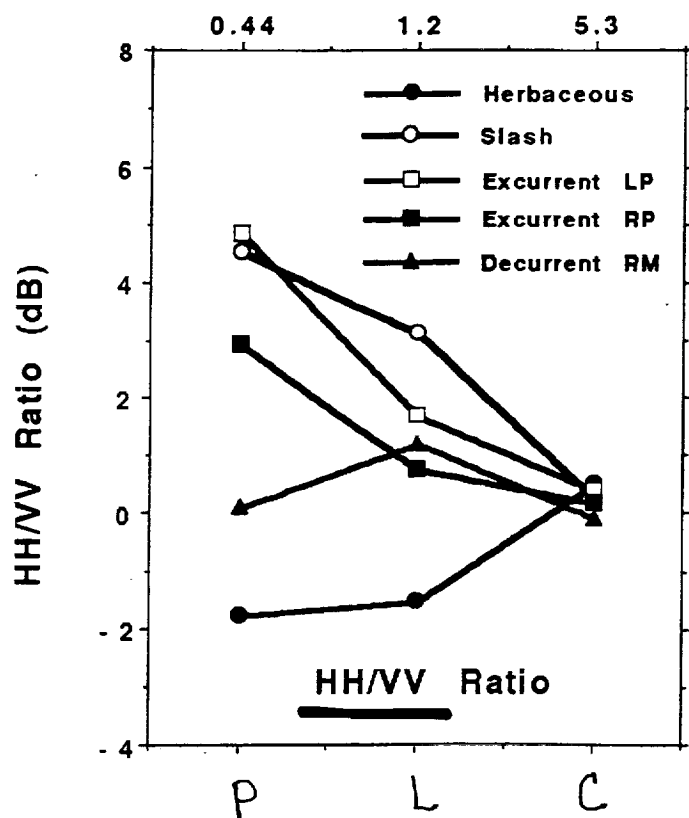
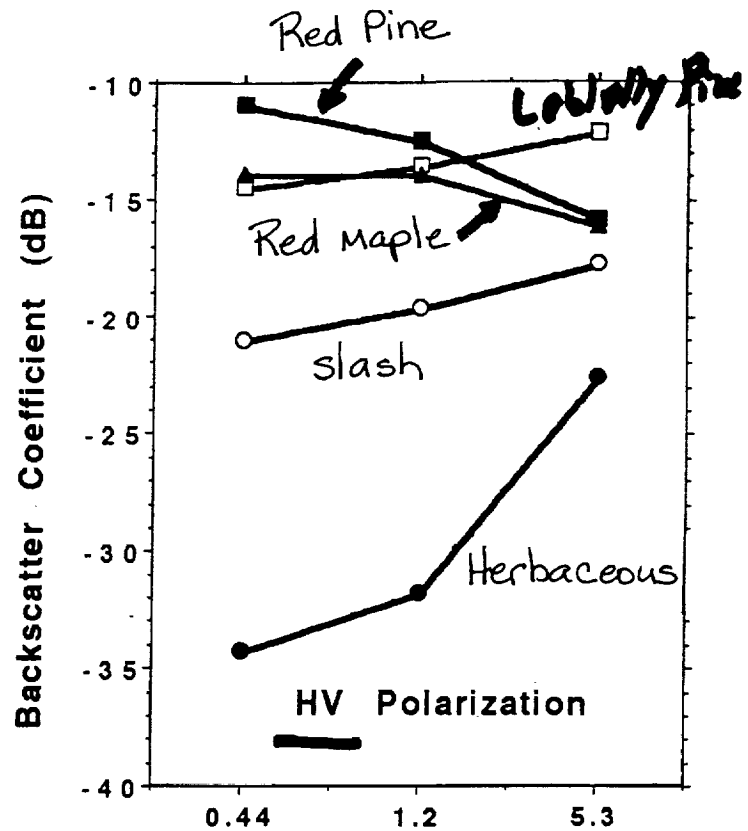
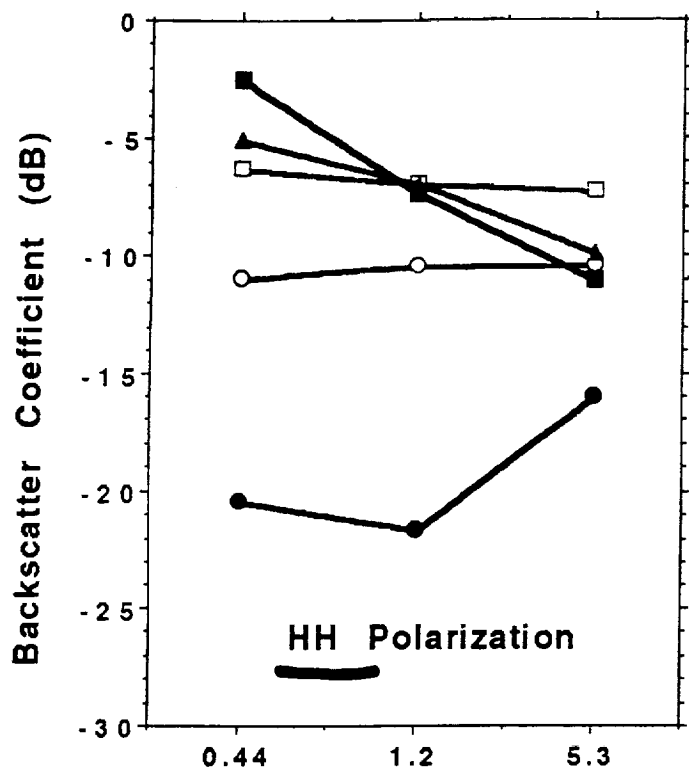


HH Polarization. 50°



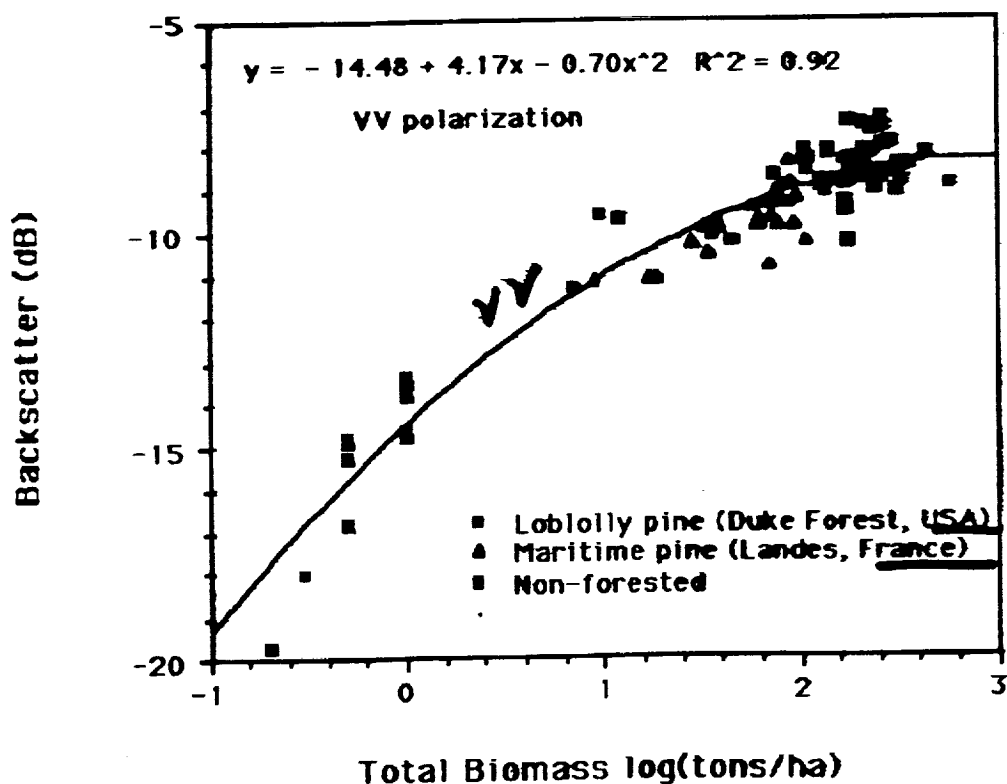
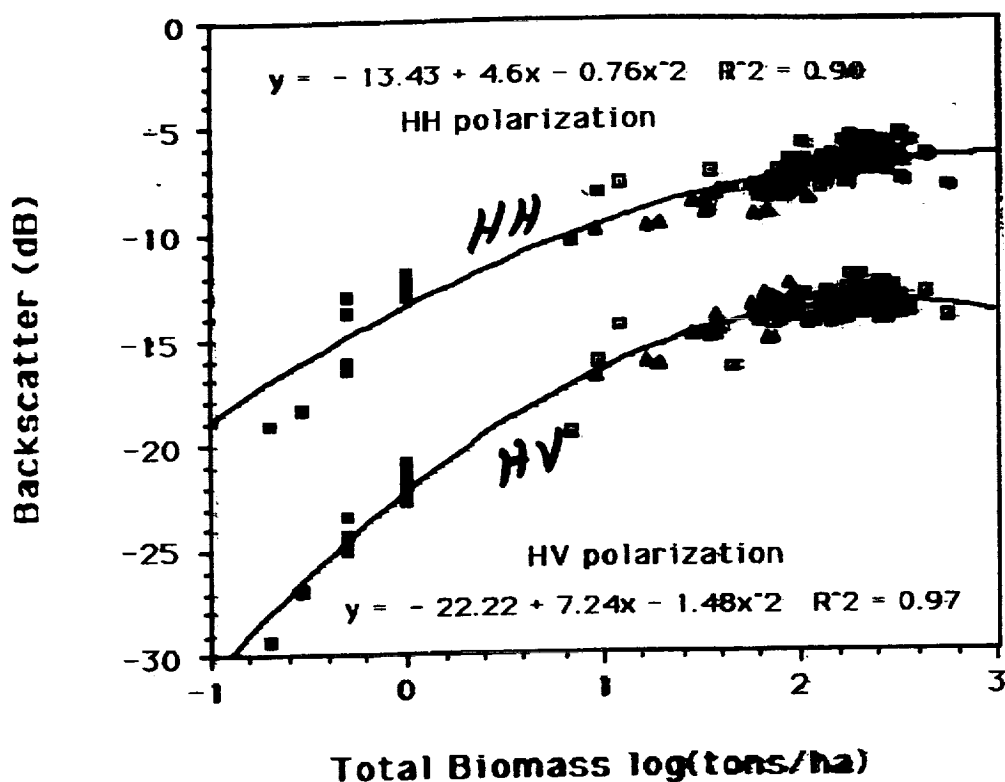
VV Polarization, 50°



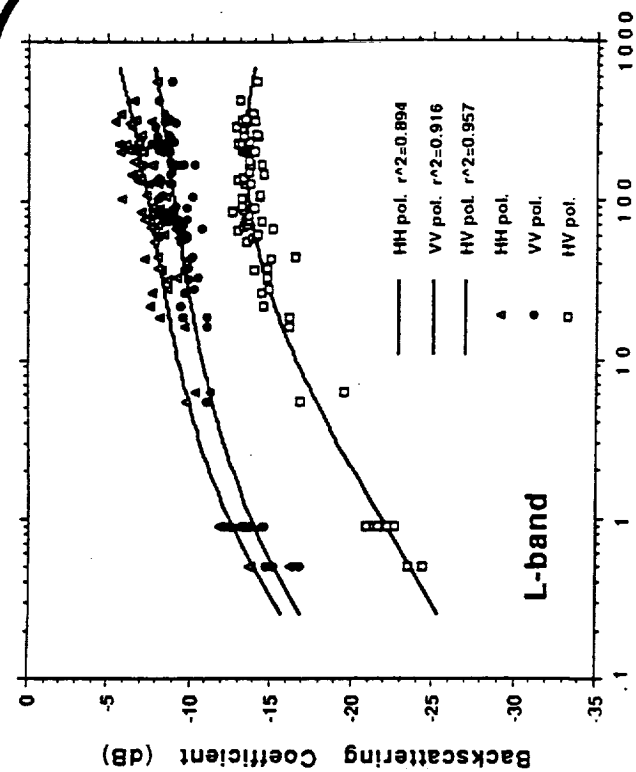
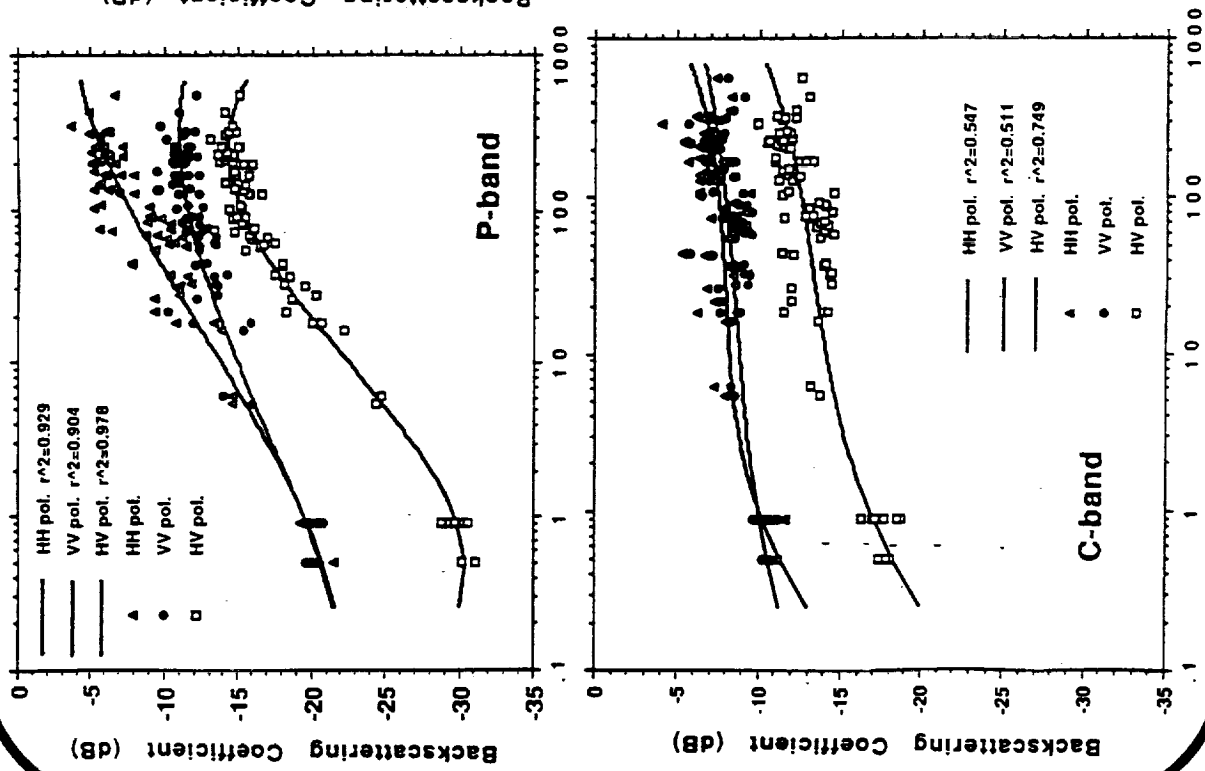


Eos SAR Mission

Calibrated AIRSAR Response at L-Band to Standing Forest Biomass

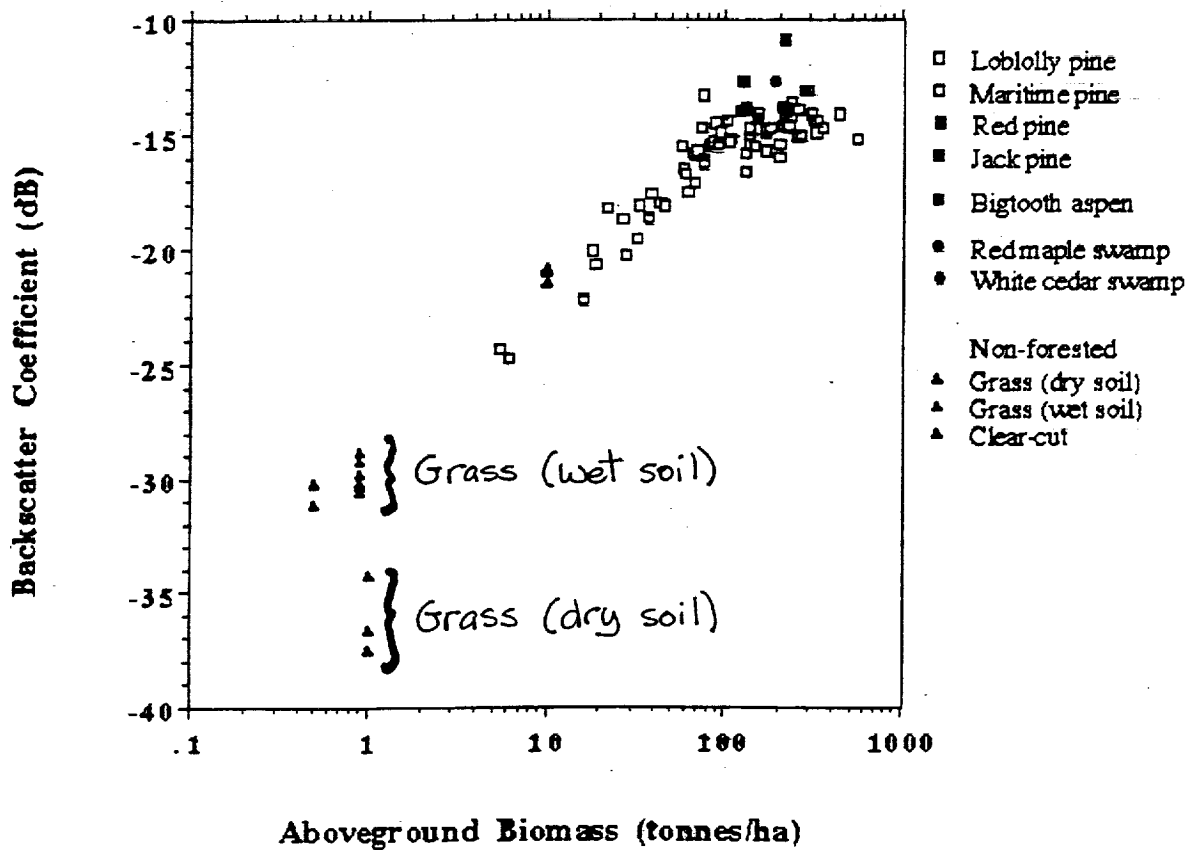


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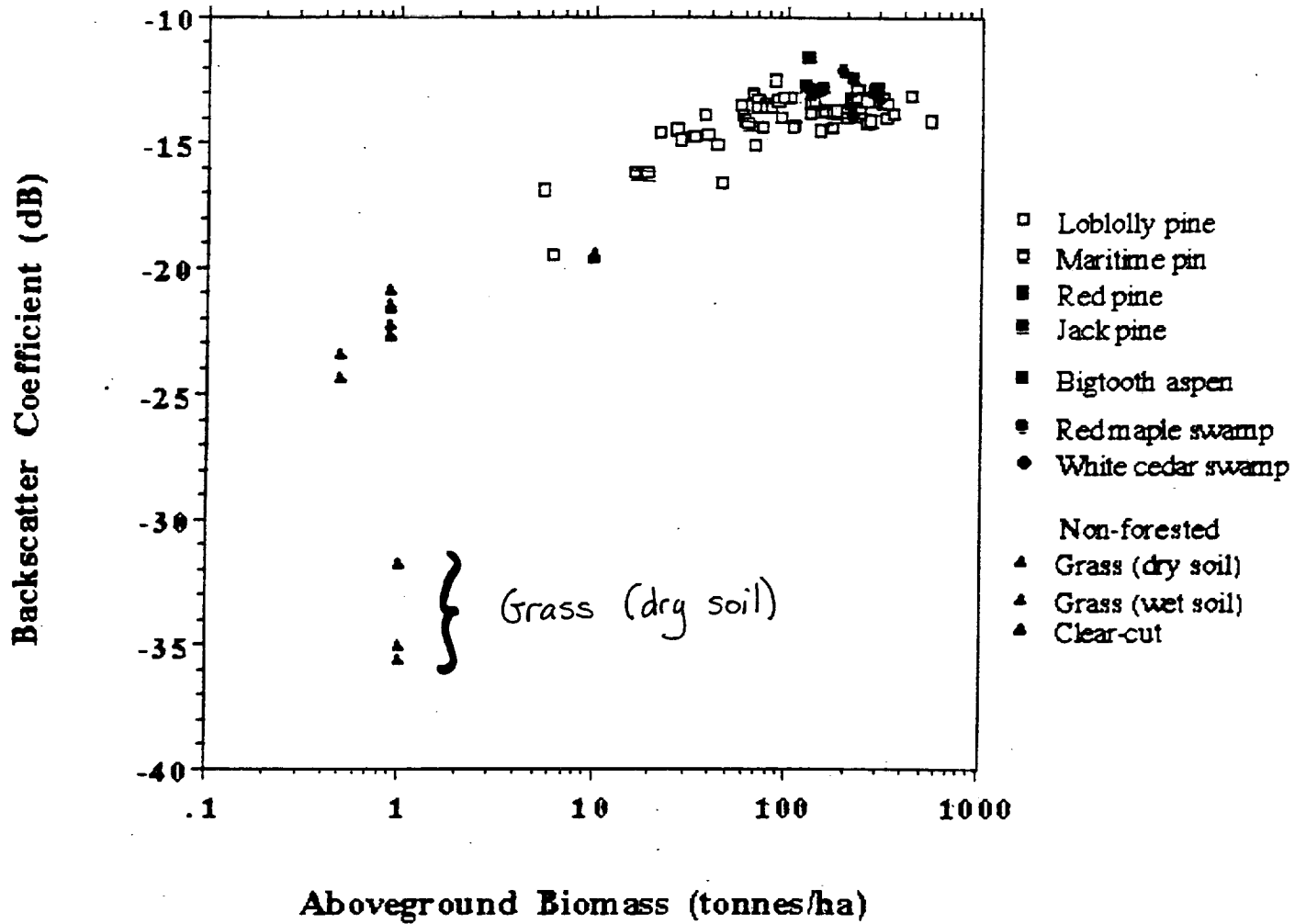
Backscatter From Loblolly
and Maritime Pines

P-band, HV-polarization

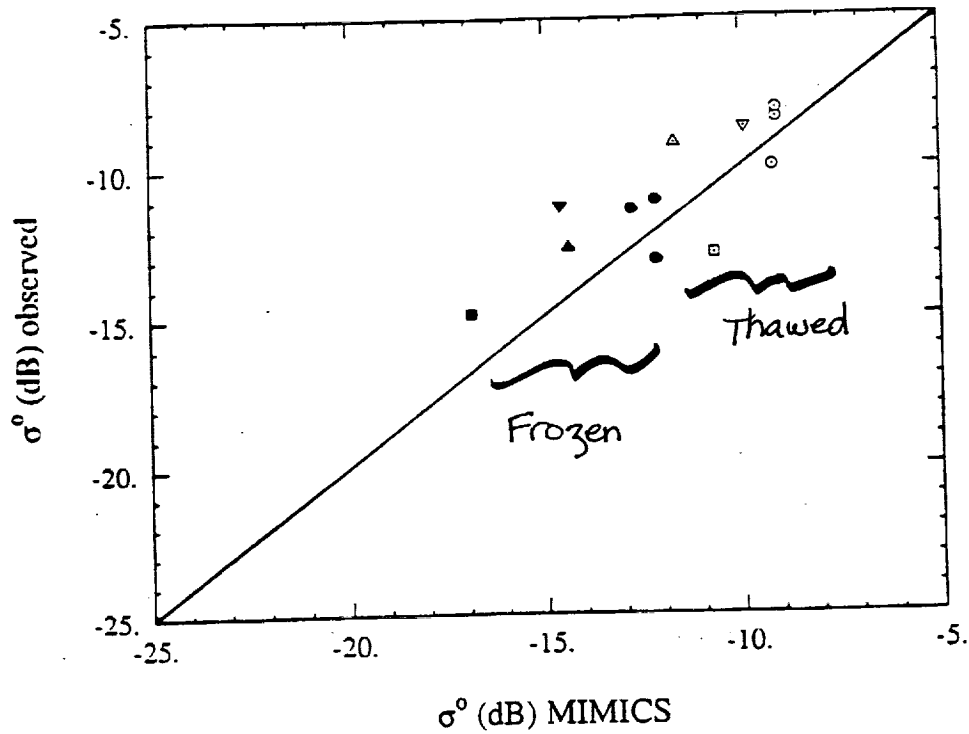


Duke Forest
Michigan Forests
Landes "

L-band, HV-polarization

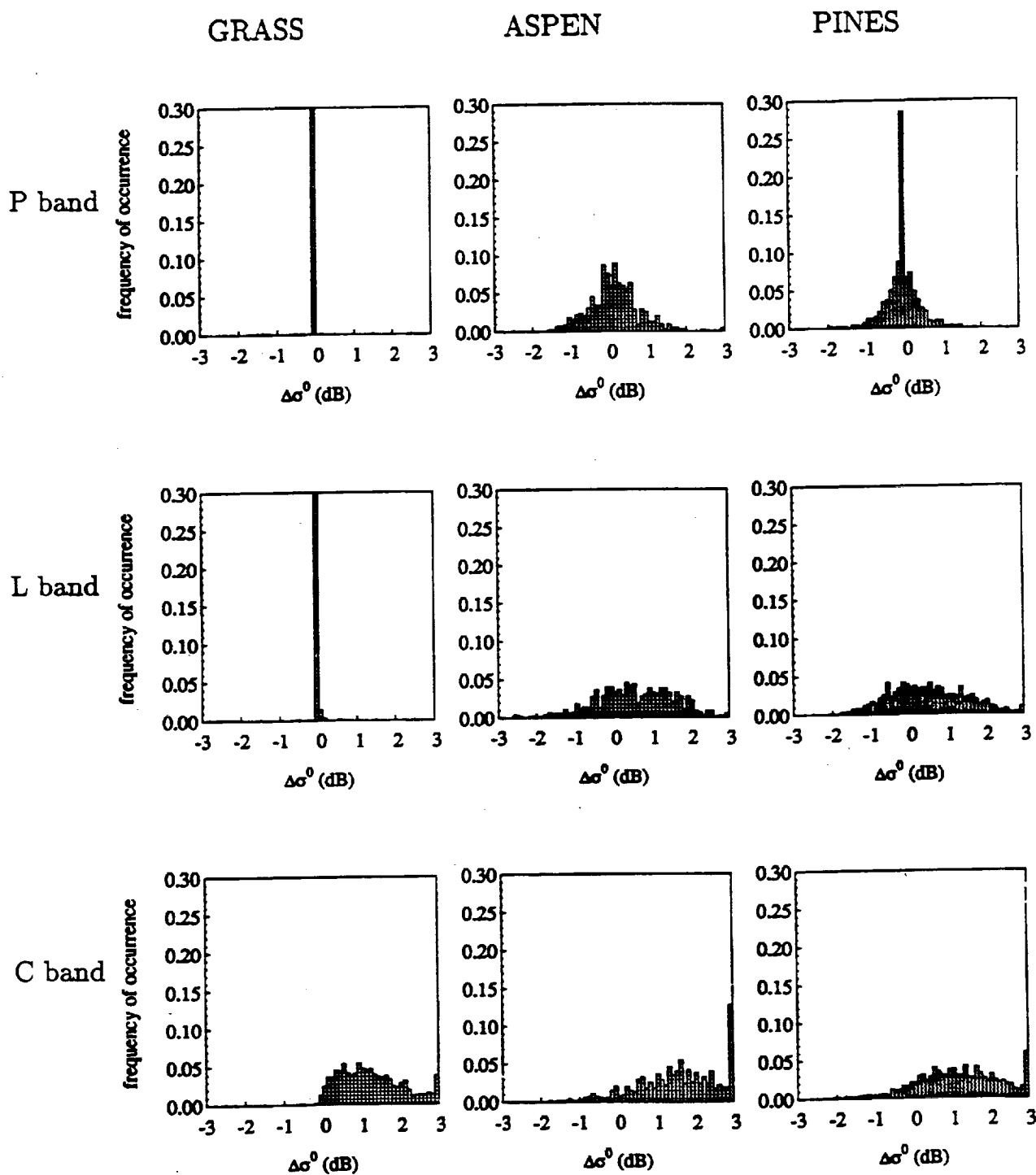


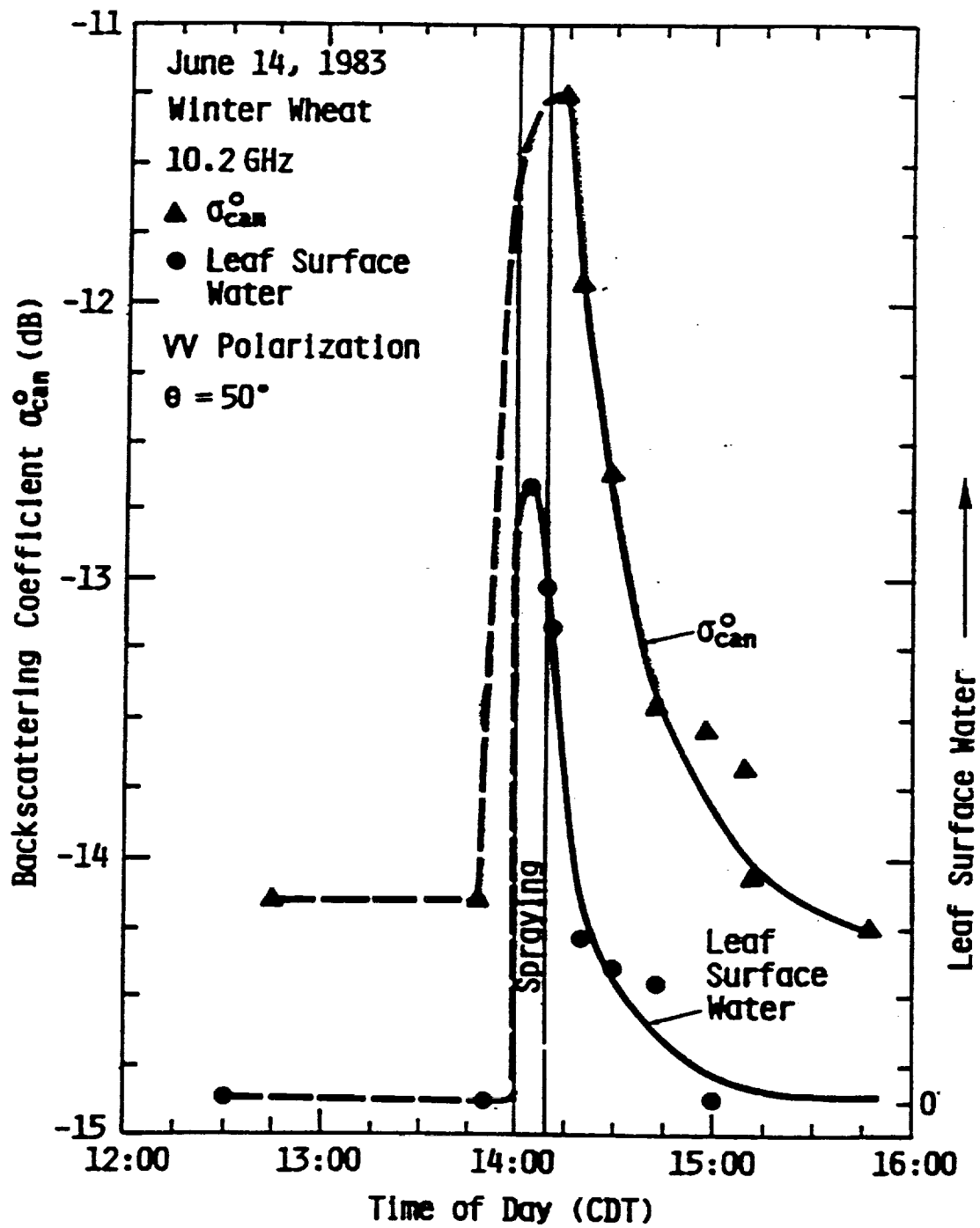
6. L-BAND SAR OBSERVATIONS IN ALASKA



- White Spruce -- Thawed
- White Spruce -- Frozen
- Black Spruce -- Thawed
- Black Spruce -- Frozen
- △ Balsam Poplar -- Thawed
- ▲ Balsam Poplar -- Frozen
- ▽ Alder -- Thawed
- ▼ Alder -- Frozen

Pellston $\Delta\sigma^0$, July 8 – July 10, HH-polarization

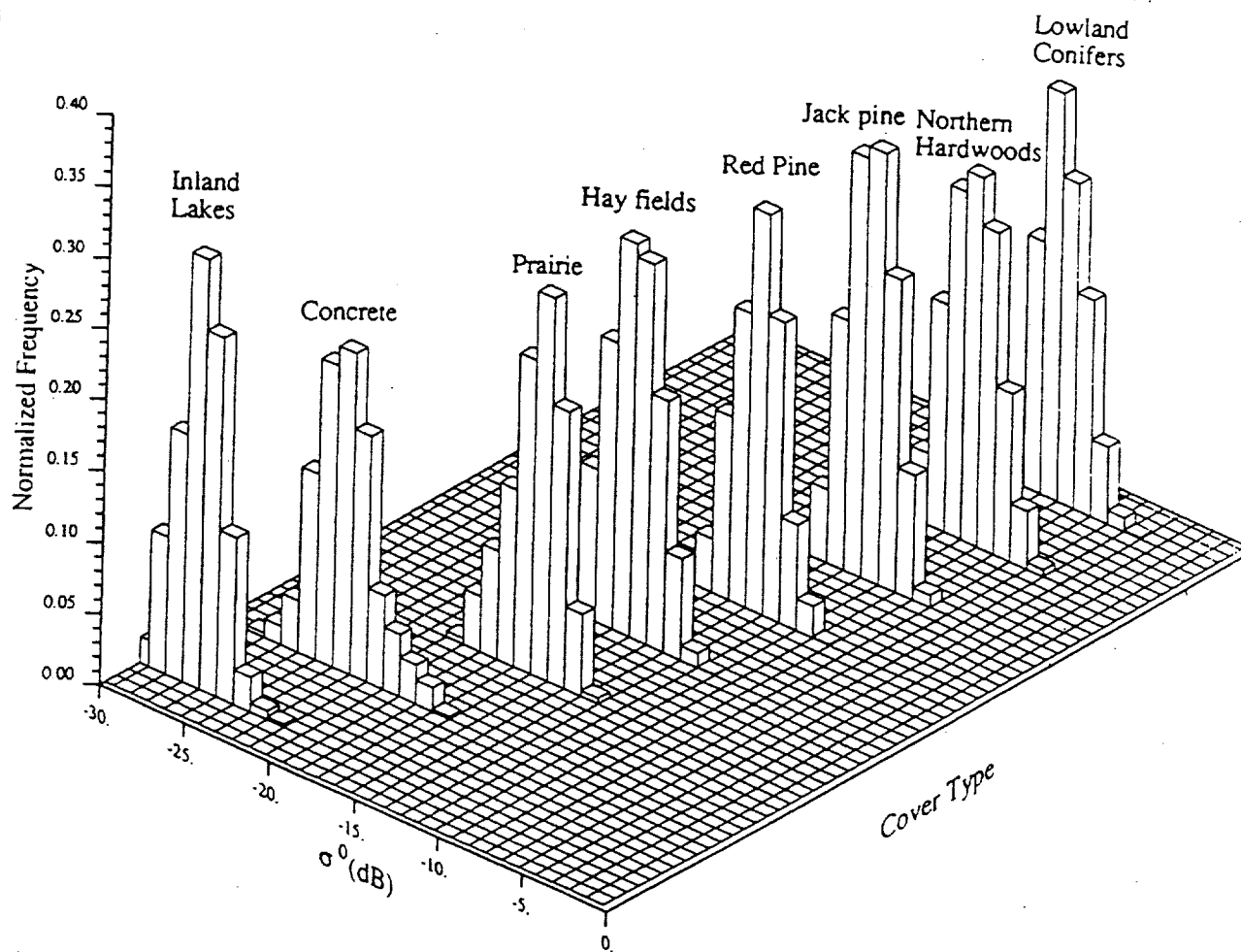




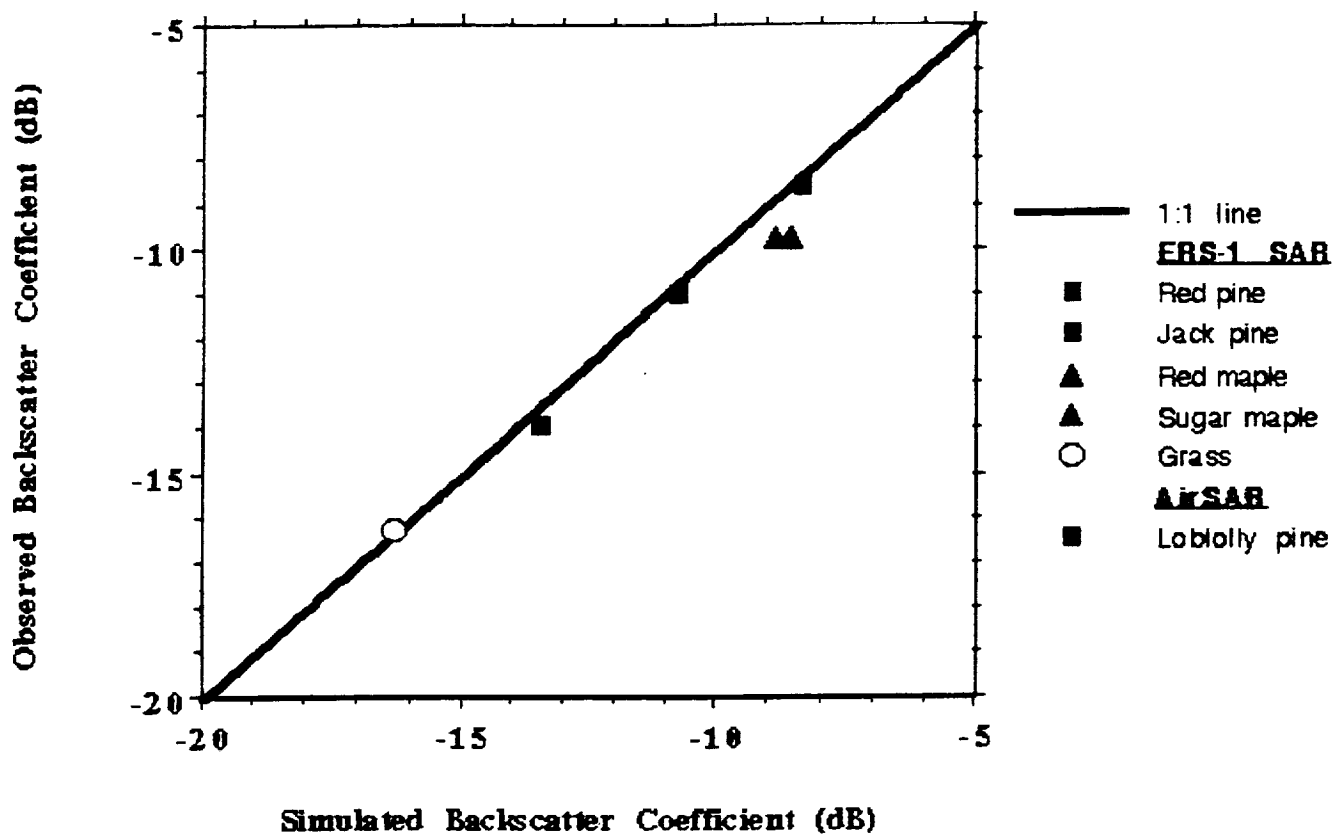
ERS-1 RESULTS

- **Class Statistics**
- **Observation *versus* Theory (MIMICS)**
- **Biomass Response (Deciduous and Coniferous)**
- **Seasonal Variation (LAI)**
 - **Deciduous**
 - **Coniferous**

ERS-1 Class Statistics for 3x3 Pixel Averages

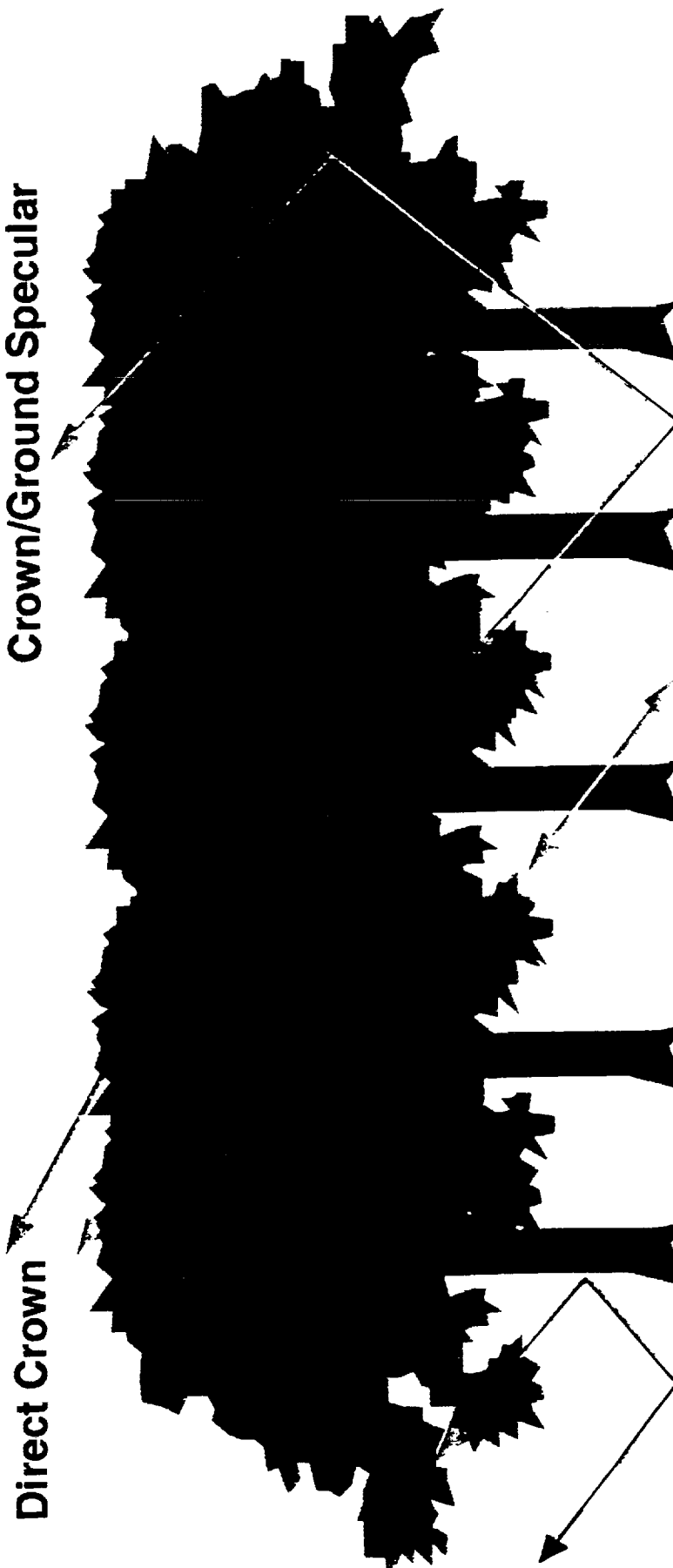


Comparison of SAR Observations with MIMICS Simulations C-band, VV-polarization



ERS-1 Backscatter Modeled by MIMICS for Northern Michigan Forests in August 1991

Dominant Mechanisms in Radar Backscattering by Forests
Crown/Ground Specular

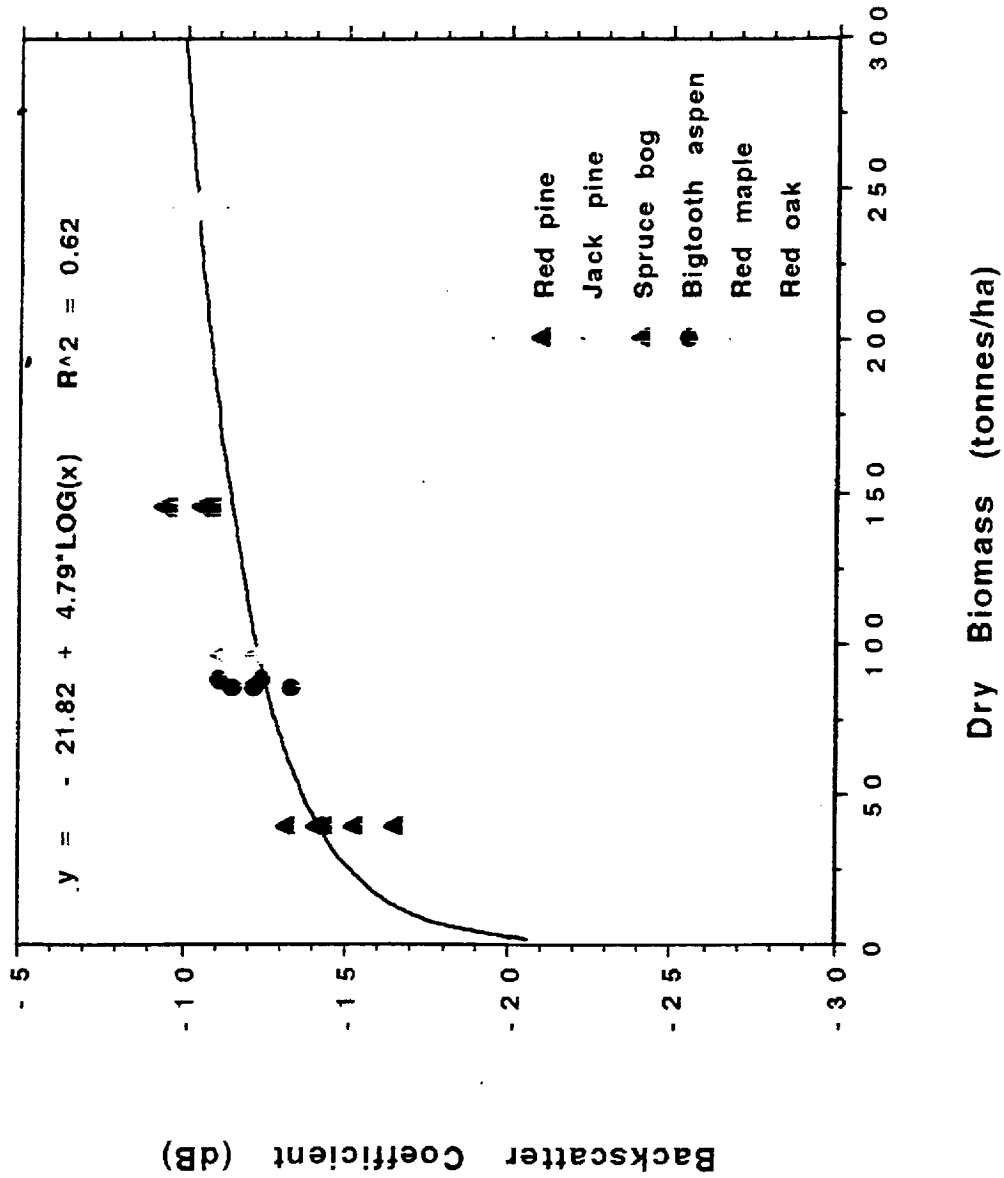


Trunk/Ground Specular Direct Ground

Dominant Specie	Percent of Total Return		Percent of Total Return		Percent of Total Return		σ^0 (dB)
	Crown	Crown/Ground	Trunk/Ground	Ground	Ground	Ground	
Red maple	95.5	0.3	4.3	-	-	-	-8.6
Sugar maple	96.4	0.4	3.2	-	-	-	-8.9
Jack pine	100	-	-	-	-	-	-10.7
Red Pine	41.3	10.4	48.1	.2	.2	.2	-13.4
grass	0.03	0.2	-	99.8	99.8	99.8	-14.4

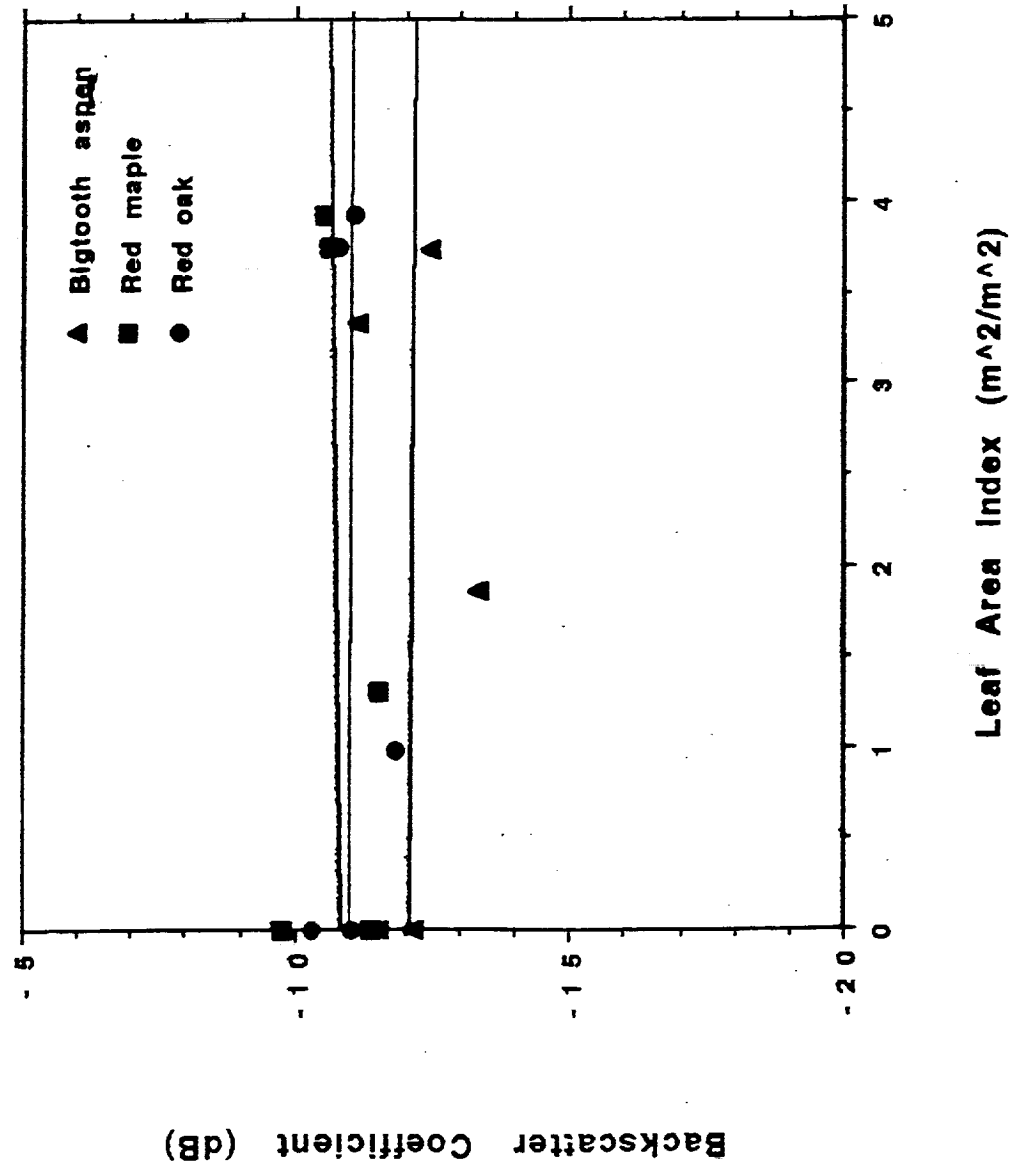
ERS-1

Dependence Upon Above Ground Forest Biomass



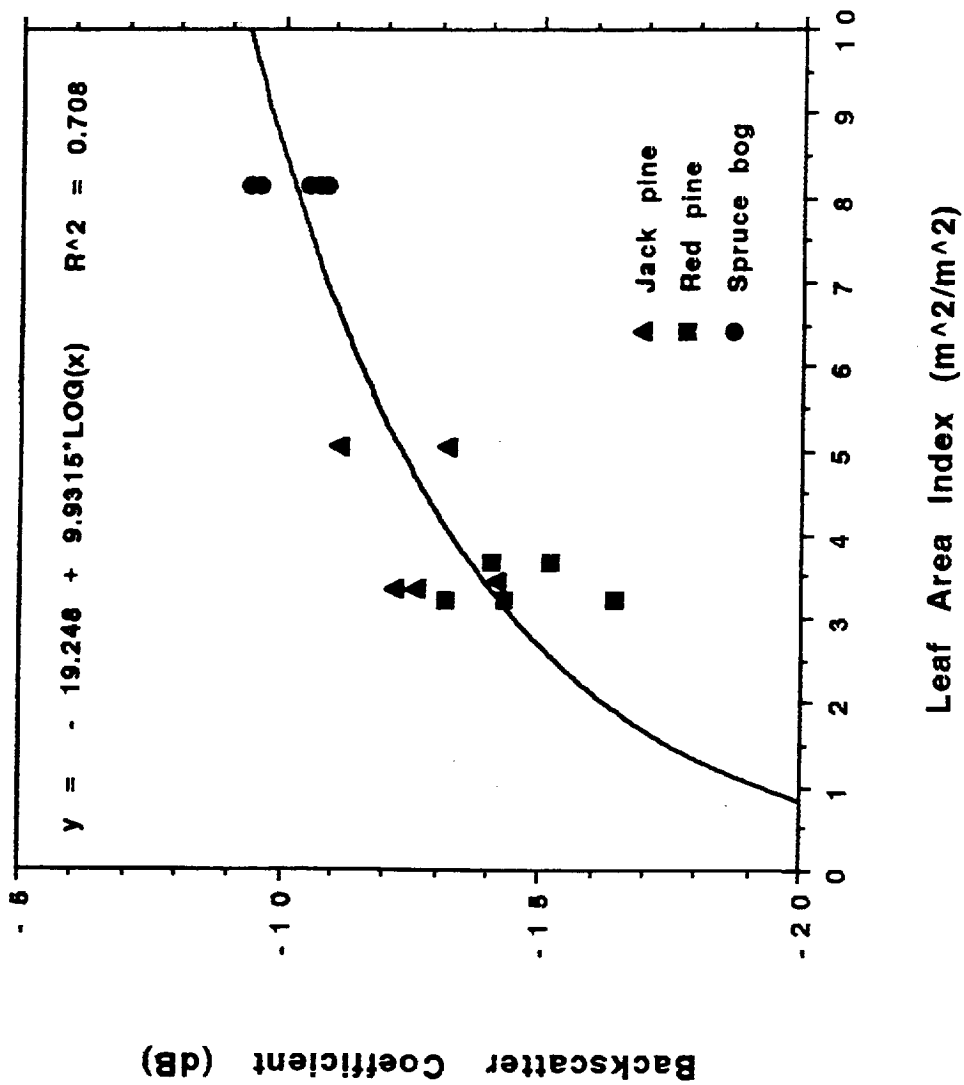
ERS-1

Backscatter vs. LAI for Deciduous Forests



ERS-1

Backscatter vs. LAI for Closed-Canopy Conifer Forests



CONCLUSIONS & RECOMMENDATIONS

I. SURFACE SCATTERING

Status

1. Retrieval of Soil Moisture and Surface Roughness

Field tested,
Some AirSAR
Verification

- **L-Band Quad-Pol** for bare soil
- P-Band Quad-Pol: extends to agricultural crops

2. Effects of Organic Debris

Demonstrated
in lab

- Extinction depends on size / λ
At P and L-Bands, only trunks and large branches are significant

II. VEGETATION SCATTERING

1. In general $\sigma^\circ = f$ (biomass, structure)

2. Extinction by crown layer increases with frequency

3. Scattering by foliage and small branches:

- negligible at P and L Bands
- dominates at C and X Bands

4. Scattering by trunks and large branches:

- dominates at P and L Bands

MIMICS,
AirSar,
ERS-1



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CONCLUSIONS & RECOMMENDATIONS

- Even P-Band is insensitive to high biomass forests (Pacific NW \approx 500 tons/ha)

6. Innundation under Forest Cover

L-Band HH

**SIR-B
AirSAR
Verified**

7. Effects of Intercepted Precipitation

- negligible at P Band
- \approx 1 dB increase or decrease at L-Band
- \approx 2 dB increase at C-Band

**AirSAR,
Scattering
Verified**

8. Freezing of Vegetation Leads to

Significant changes in σ° at all Bands

**AirSAR,
MIMICS
Verified**

9. Deforestation Readily Detectable at

P and **L-Band**

**SIR-B,
AirSAR**

10. LAI Foliar Biomass Estimation

C-Band Quad or X-Band

**MIMICS,
Field,
AirSAR**

11. Multi-Date Observations: Very Powerful Tool

- Requires good Relative Calibration (Stability) $\approx \pm 1$ dB
- Requires good Absolute Calibration $\approx \pm 1$ dB

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